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HANDBOOK

FOR

FIELD GEOLOGISTS

BY

C. W. HAYES, Ph.D.

Chief Geologist, United States Geological Survey

SECOND EDITION, THOROUGHLY REVISED

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PREFACE

Members of the U. S. Geological Survey have for some time felt the need of a convenient and concise description of geologic field methods. An attempt to meet this need was made by the publication, in 1908, of a Handbook for Field Geologists in the United States Geological Survey. This work was intended for distribution only to members of the Survey, and only a small edition was issued. The requests for copies of the Handbook, which have come in from members of State Surveys, teachers, mining geologists, and others, indicate a genuine need for something of the kind among geologists generally. The present work is written in response to this evident demand. The Survey Handbook has been used in the preparation of this work, omitting those instructions which apply only to members of the Government Survey, and enlarging upon certain features which will be of service to students preparing for work in field geology.

In geologic field work, as in most other things, there are certain methods of procedure which have been found by experience better than others, and poor or wrong methods result in loss of efficiency. While many of the suggestions given may appear entirely too elementary, and to cover points on which instructions are unnecessary, it is my experience that mistakes in these simple matters are by no means confined to beginners.

Field geologists, and particularly students using this book, are cautioned against its abuse. Directions for making and recording observations and for the use of the schedules are intended to insure thoroughness and system, not to relieve the observer of the necessity for thought. It would be a misfortune if they should hamper originality or reduce the work to a merely mechanical process.

The work of the field geologist presents great diversity, and while the more common types which will be encountered in North America are provided for in the following instructions, all conditions cannot be foreseen, and the geologist must modify methods and adapt them to the particular needs of his work. This is notably true in regions difficult of access, or where unusual obstacles to travel and observation must be overcome, as in parts of Canada and Alaska and most tropical regions. Special methods must be devised to meet such special conditions, and the geologist's success will be proportional to his adaptability.

For the material included in a manual of this kind no great amount of originality can be claimed. It is necessarily in large measure a compilation. Suggestions regarding the matter to be included and the manner of treatment, have been invited from my colleagues, and these suggestions have been freely used. In the preparation of the schedules in particular, has valuable assistance been given by those especially familiar with the subjects treated. Specific acknowledgment for such assistance is given on subsequent pages.

C. W. Hayes.

Washington, D. C., Feb. 22, 1909.

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PART I

GENERAL INSTRUCTIONS

PRE-REQUISITES FOR A FIELD GEOLOGIST

Physical and mental qualities. To insure even a moderate degree of success as a field geologist one must possess certain physical and mental qualities, the lack of which may be in no wise to one's discredit and may involve no particular disability in many other professions. It is well therefore to determine in advance of the long apprenticeship required whether or not the candidate possesses these necessary pre-requisites. A responsibility not always realized rests upon teachers of geology to explain fully to their students the requirements of the profession, and to divert from it those who are manifestly lacking in the qualities essential for success.

The first qualification is a good physique and a strong constitution, for sooner or later severe and long-continued physical exertion will be required, and a defect in ability to sustain this exertion will be a serious handicap.

The second is adaptability. Few occupations present so wide a diversity in conditions under which work must be carried on as that of the field geologist. His surroundings may vary all the way from the luxuries of a summer resort hotel to the bare necessities which he can pack on his back, and he must be able to adapt himself with equal readiness to either extreme. If one cannot so adapt himself, but is dependent on any particular kind of surroundings, he should abandon the idea of becoming a field

geologist, for he will find the occupation extremely unsatisfactory.

A geologist must possess a practical knowledge of horsemanship, of boating, and of general woodcraft, so that he will be equally at home in the saddle, in the canoe, or on foot in a trackless forest. One is fortunate who has already acquired this practical knowledge, but if he does not possess it he must be sure that he has an aptitude for acquiring it quickly.

Training. It is questionable if geology can be regarded as a distinct science, in the same sense as chemistry or physics. More properly, it is the application of a number of special sciences to the solution of a particular class of problems. It follows that the best preparation for geologic work is a thorough grounding in these fundamental sciences, particularly chemistry, physics, zoology, and botany. Mathematics and modern languages are also essential. The student who is thoroughly trained in the principles of these sciences will readily grasp their special application and will have a sound basis on which to build up the structure of geologic facts and theories to be acquired in the field. The student is therefore advised to plan his college and university work so as to acquire this fundamental training, if necessary, even at the expense of certain geologic courses which deal with subjects that can be much better covered in connection with subsequent field work. If he continues in geology as a profession, he will have abundant opportunity to acquire geologic facts, but he will probably have neither opportunity nor time to study chemistry or physics after leaving college.

It should be clearly understood that this advice is addressed only to those who expect to become professional geologists; it certainly does not apply to students who expect to follow other lines of pure or applied sciences, or who are taking scientific studies for the sake of the breadth of culture which they alone can give.

Second in importance only to a thorough grounding in the physical sciences is ability to write clear and concise English. Although the application of this part of a geologist's training will come chiefly in the presentation of his results, it is so necessary a complement to successful field work that it must be regarded as an essential pre-requisite. It is assumed that the successful

geologist will be a clear and logical thinker, and it should be equally a matter of course that his writing will be clear and logical. The highest literary style can be attained by a few only, but clearness is within the reach of all who are willing to take the pains necessary for acquiring it.

CLASSIFICATION OF SURVEYS

Official surveys. By far the larger part of the systematic work in field geology in North America is done under the auspices of official surveys. Federal surveys are maintained in Canada, the United States, and Mexico; also provincial or state surveys in Ontario and in thirty-five of the states.* The form and functions of these organizations varies somewhat widely, but nearly all are engaged in some form of field work, although a few are primarily bureaus of information.

The degree of specialization in these organizations depends chiefly on the number of men in their scientific force, and naturally is greatest in the federal surveys. The need for specialists in many of the state surveys is met in a measure by the occasional employment of university professors. The larger organizations, both state and federal, are under the classified civil service regulations, and in these, appointments are made only after competitive examination or other impartial test of fitness.

Appointments are usually made to the lower grades and service as an assistant for a period of one to three years is required before the geologist is given independent work. The length of this apprenticeship depends largely upon previous training, and it is therefore highly important for the beginner to become early and thoroughly familiar with the best field methods.

Educational surveys. Most teachers of geology recognize that certain parts of the subject can be properly taught only in the field, and therefore include field courses as a regular part of their instruction. This is generally confined of necessity to the immediate vicinity of the institution, but occasionally a more

* Information concerning the organization and personnel of these official surveys is given in Appendix I to this volume.

remote field is selected, and systematic work is carried on which may result in definite contributions to geologic knowledge. In selecting a locality for such educational work several considerations should be kept in mind. The region chosen should present some diversity in geologic phenomena, but should not be so complicated as to prevent the beginner from reaching definite results through his own exertions. He should not have too early impressed upon him the uncertainty which attaches to many geologic conclusions, but should acquire a proper degree of confidence in his results. The area should not be too large for thorough work, nor should it be so small that the student will fail to have impressed upon him the important fact that, later, quantity as well as quality will be demanded of him. It is generally best to require the construction of a topographic base on which to represent the geology, even if the region selected is already mapped, for the ability to construct a good topographic map is a fundamental part of a geologist's training.

The beginner learns most from his own mistakes, but only when he is obliged to correct them himself. It is essential, therefore, that while he should be thrown early on his own resources, his results should be most carefully checked by some one more experienced. The practice of sending out untrained men to do even the simplest forms of field work without supervision, and accepting their results without thorough examination, is equally bad for geology and for the geologist.

Private economic surveys. Mining operators are rapidly coming to a fuller appreciation of the intimate relation between geologic conditions and occurrence of ore bodies. The demands for geologic surveys of mining properties are therefore increasing. This is especially true with the larger and better organized companies. Such surveys differ in no important respect from certain of those made by government organizations, except that they are generally confined to a smaller territory, and the economic results are not immediately made public. Surveys of this kind are in progress in connection with the development of coal, oil, iron-ore, and the metalliferous ores in many parts of the country, and the field methods applicable are exactly the same as in public surveys of similar scope and purpose.

Relations to the public. The movements of the field geologist are calculated to excite a lively curiosity in the mind of the onlooker, and the geologist must expect to be assailed by a great number of questions. It is generally advisable to take the necessary time and trouble to explain to any one making serious inquiry exactly what is the object of the work. This is of course essential where the survey is official and carried on at government expense. The opportunity to educate the people of a region in which work is being done to an appreciation of the nature and importance of geologic surveys should be utilized so far as possible.

Objection is sometimes made to entry on private property, but the geologist will generally be able to overcome such objection by an explanation of the character and object of his work. The most strenuous objection can often be changed into hearty coöperation by the exercise of a little tact.

Laws have been enacted in Arizona, California, Illinois, Maine, Montana, New York, Ohio, Pennsylvania, and Washington, granting authority to officials of the State and Federal Surveys to enter on private property when engaged in official work. Even in these states, however, the policy of conciliation is generally preferable to an insistence on the legal right.

All field geologists, particularly those engaged in economic work, should recognize their obligations in relation to the information which they acquire in connection with their work. Any appearance or suspicion of favoritism in giving out the results of official surveys should be avoided, and all who are interested in the results of the work should be assured of fair and equal participation in any benefits to be derived from them. It is usually regarded as proper and permissible to communicate orally to the owner or manager of a mineral property during the progress of its investigation such information regarding the geology of that property as may be of value in its development, but written statements should be avoided lest they be used for promoting or unduly enhancing values.

Information of a confidential character, such as drill records, mine maps, statistics of production and analyses, supplied by private parties or corporations, should be most carefully guarded

and used strictly in accordance with the conditions stipulated by the persons furnishing it.

PREPARATION FOR FIELD WORK

Organization. The *party* is the natural administrative unit in an organization engaged in field work, and there should be no room for misunderstanding as to who is in charge of the party, and hence responsible for its conduct. The chief of party should be furnished written instructions which are clear and definite as to essentials, particularly location, scope, and purpose of the work. Since contingencies which cannot be foreseen are sure to arise, it is better to leave a certain amount of discretion with the party chief, rather than to hamper him with minute instructions. He should be impressed with the fact that *results* are required, and that they must be proportionate in quantity and quality to the expenditure. After receiving his instructions the chief of party should adhere to them until they are replaced or modified by other written instructions, and in no case should he make any material change on oral instructions from any source. If the field work is limited by the amount of money which can be expended on it, the exact allotment should be known in advance, in order that definite units may be brought to completion within the given limitations.

Scientific and technical field assistants will generally be selected and employed in advance by the proper administrative officer, but the chief of party should be consulted in such selection and their personal and scientific qualifications should be satisfactory to him.

The selection and employment of necessary laborers, including cooks, teamsters, packers, etc., should be left to the chief of party. As the efficiency of the party is largely dependent on the capacity and willingness of the laborers, care should be exercised in their selection. Excellent results have been obtained in many cases by selecting college students for these positions.

Purpose of the work. Obviously, the first step in preparation for the field is a determination of the exact purpose of the

work. Upon this will depend the character of field methods and outfit adopted. These will vary widely in accord with varying circumstances. The purpose of the work may be a detailed study of a small area or a rapid reconnaissance of a very large one. It may involve operations from a single station or the collection of information during rapid travel through the country, and with no possibility of departing from a single route. The object may be purely economic or purely scientific, or it may involve both considerations in all proportions.

Field work may be classified as follows:

1. *Areal, structural, and stratigraphic geology, with incidental study of economic mineral deposits.*

The primary purpose of this class of work is the preparation of a geologic map which, with the accompanying structure sections, shall show the distribution of geologic formations at the land surface, and their attitude and position below the surface. It may, at the same time, cover a comprehensive study of the mineral resources or may be simply intended to furnish a basis for further study of the economic geology, by showing the surface and underground distribution of the formations with which the mineral deposits are known to be associated. The character of these deposits will influence the degree of refinement with which the work must be done and the points to which special attention is directed. For example, if the region contains coal or oil, it is highly important that the underground structure be accurately determined so that the depth to a particular stratum may be predicted within a few feet at any point on the area mapped. Data from which the underground contours of a selected stratum may be constructed must therefore be secured in addition to those required for structure sections. If, on the other hand, the region contains only such deposits as are worked at the surface, as limonite iron-ore, building stone, etc., the underground structure is less important, but it is necessary to map outcrops of particular beds very accurately.

The scale on which the results of field work are to be published should be considered in advance, and the degree of refinement suited to this scale. It will often be necessary to work certain parts of the area in greater detail than can be shown on the final

map, in order to determine the key to intricate structural problems, but considerations of economy and the practicability of cartographic representation fix a rigid limit upon such detailed work. On the other hand, the work should be as nearly up to the scale as the limitations of time and allotment for the work permit. In short, the field geologist must avoid the opposite extremes of becoming lost in a mass of detail which cannot be represented, and indulging in generalizations which seriously detract from the value of the map. The proper adjustment of the field work between these extremes is secured only by experience and intelligent consideration of the purpose of the work.

The great variety of uses to which maps resulting from this class of field work will be put should be kept in mind. They should be adapted to educational purposes, to the economical and conservative development of mineral deposits, to the determination of water supply, both surface and underground, to the location of roads and road materials, to the study of character and distribution of soils, to the study of forests and reforestation, the classification of public lands, etc.

2. *Economic geology with incidental study of areal, structural, and stratigraphic problems.*

The primary purpose of this class of work is the determination of the geologic relations of particular mineral deposits. The study of areal distribution of formations and underground structure is incidental to this object, though generally essential. The area covered by such work is generally more restricted than in the former class, and the work is done in greater detail and on a larger scale. In case of mineral deposits having wide distribution, as coal, the scale of the work and the methods which should be employed do not differ materially from the first class except that more attention is given to the study of the coal itself, to its composition and its variation from place to place, and to all of the conditions which will affect its economical development.

In case of metalliferous ores, particularly of gold, silver, and copper, the area within which the geology is to be studied is usually confined to a few square miles, but within these limits it must be examined in an extremely detailed manner and all

possible lines of evidence followed, both on the surface and underground. In such work no details of structure or petrology can be overlooked, for it is upon these that conclusions as to genesis and extent of the ores must rest.

The work of the economic geologist should be clearly differentiated from that of the mining engineer who is concerned primarily with determinations of amount and value of ore in the deposit and methods of economical exploitation. Both functions may be performed by the same person, but they should be kept entirely distinct.

3. *Investigation of the geology of mineral deposits.*

Work of this class is of two kinds: first, the study of ore deposits in districts where the areal and structural geology has already been done, and second, general study of some particular kind of deposits. The former differs in no way from Class 2 above, except that it is confined strictly to the mineral deposits, while the latter covers so many widely separated deposits that opportunity is generally afforded only for a hasty reconnaissance of the surrounding geology without detailed mapping.

4. *Investigation of paleontologic, petrographic and stratigraphic geology.*

The paleontologist and petrographer are no longer content, as formerly, to work only in the labroatory, but appreciate the necessity of field observation. Their work can be done most advantageously in immediate coöperation with the work of the field geologist, for these specialists furnish the standards for classification and correlation on which the field geologist must rely. It is highly desirable, therefore, that the correct standards should be established in the field by means of preliminary paleontologic and petrographic determinations.

In addition to the above, and independently of areal surveys, studies are desirable of particular localities where important stratigraphic sections or groups of rocks occur. These are chiefly contributory to pure geology, though they may have important economic applications.

5. *Investigation of glacial and physiographic geology.*

While the study of glacial deposits is in large measure purely areal, the methods and criteria employed are so specialized that

it is placed in a separate class. In addition to the classification based on character and origin of the materials making up glacial formations, surface form is more important than in other classes of work, and glacial geology therefore merges into physiography, in which *form* is the principal factor considered. It is frequently desirable to have the glacial and physiographic geology worked separately from the areal and structural geology of the hard rocks. This is a degree of specialization which is not always practicable, but is productive of the best results.

Previous work. Before taking the field the chief of party (and his assistants also, if possible) should familiarize himself with previous geologic work, published and unpublished, relating to the region. He should endeavor to find out the amount of ascertained fact, as distinguished from interference, represented on each map. Such previous work should be utilized to the utmost, but the geologist should guard, on the one hand, against following former conclusions slavishly and, on the other, against going out of his way to prove his predecessor in the wrong.

If geologic maps of the region have been published, an extra copy of each should be obtained, if possible, and so mounted as to be convenient for use in the field. It is not generally desirable to carry a large amount of literature into the field, but exception should be made in favor of reports to which frequent reference will be made during the progress of the work.

Topographic data. All available maps relating to the region to be studied should be procured. Atlas sheets for field use should be sectioned and mounted on cloth for folding or on leaves for insertion in the notebook. If notes are placed directly on the map the latter method is preferable, as there is less liability of loss. A convenient method of protecting from injury a folded map, mounted or unmounted, is to carry it in a transparent celluloid pocket which may be fastened on the inside of the notebook cover. By proper folding, any part of the map can thus be consulted without removing it from the case. A few extra copies of the atlas sheets covering quadrangles on which work is to be done should be taken into the field. If no topographic map is available, or if the map is known to be inadequate or inaccurate, special efforts should be made to procure all available

topographic data, such as railroad locations and profiles, ditch surveys, private mining-district maps, land office township plats, etc. Many of these data must be obtained by correspondence, which requires time and should not be postponed until the eve of taking the field.

Miscellaneous information. If the field to which a chief of party is assigned is a new one he should, before leaving the office, gain all information possible concerning climate, vegetation, roads and trails, inhabitants, supply points, railroad, stage, mail, express, and telegraphic facilities, and all other matters which will have a bearing on the method of carrying on the work and affect its economy and efficiency. Much of this information can usually be obtained by conference in the office with topographers and others familiar with the region, but some must generally be secured through correspondence.

FIELD OUTFIT

Instruments. For ordinary geologic field work the necessary equipment of instruments is neither elaborate nor expensive. The following list includes all which will be needed under ordinary conditions. They are arranged in order of importance.

Compass. Should be supplied with a clinometer and movable circle for adjustment for magnetic declination. The Gurley aluminum geologic compass with staff socket, is best suited for many kinds of work, particularly for tracing land lines where considerable accuracy is required. The Brunton pocket transit shown in Fig. 1, is compact, convenient, and accurate. It is adapted to a variety of purposes, and is probably the best type for general geologic work. It can be used as a prismatic or sighting compass, clinometer and hand level, and is especially adapted for mine surveys. In regions where there is strong local magnetic attraction, a dial compass is required, with graduation for the particular latitude at which it is to be used.

Hammer. Should weigh from one to one and a quarter pounds without handle. The type shown in Fig. 2*a*, is the one adapted to most purposes, though some geologists prefer a chisel point,

Fig. 2*b*, instead of the pick. This is useful in soft rocks or where digging must be done, as on a coal crop. Only the best steel

FIG. 1.—Brunton pocket-transit.

should be used, and tempered so that it will not chip. A trimming hammer, Fig. 2*c*, is desirable where museum specimens are to be collected. It should weigh about six ounces.

Collecting bag. Should be made of strong canvas or leather, about 12×12×4 inches, with carrying strap to pass entirely around it, and loops or hooks to attach to a belt. It should have a double back, forming a pocket for maps and a smaller pocket

FIG. 2.—Geological hammers.

on the front for notebook. The flap should be ample to protect its contents from rain. A larger bag will be needed by geologists making fossil collections, and it should be provided with two shoulder straps for use as a knapsack.

In case much work is done on horseback, saddle pockets will

be found very useful. The pockets should be about $12 \times 12 \times 4$ inches, and one of them should be attached by rings and snap hooks, so that it can be readily removed and used as an ordinary collecting bag.

Aneroid. Should be selected with reference to the region in which it is to be used, and should be the lowest reading permitted by the maximum altitude,—3000′, 5000′, 10,000′, etc. The aneroid should be carried in a snug-fitting leather case with loops for belt, or in shirt pocket with buttoned flap, never loose in coat pocket or collecting bag, or by a strap over the shoulder.

Hand level. Needed to supplement the aneroid where accurate stratigraphic work is to be done. For ordinary work a Brunton pocket transit will answer, but if much leveling is done a Locke or Abney level should be provided. The Abney level may also be used as a clinometer and for determination of vertical angles. As explained on page 25, it may be desirable, under certain conditions, to use a telescopic hand level with staff socket.

Field glass. Zeiss anistigmatic is preferred, on account of compactness, and the monocular is preferable to the binocular for the same reason. Very little use will be made of field glasses in a region of low relief, particularly if forested. They are needed in high or unforested regions.

Camera. Should fold compactly. Most field purposes are served by a $4\frac{1}{4} \times 5\frac{1}{2}$, unless the geologist is a skilled photographer. Larger sizes should always be used with tripod. Roll films or film packs should be used unless the facilities for handling glass plates are exceptionally good.

Plane table. Fifteen-inch traverse table with open sight alidade or Graton alidade (for description see page 61), will serve most geologic purposes. In exceptional cases, where an accurate topographic base is to be made by triangulation methods, a Johnson plane table and telescopic alidade will be required.

Sketching case. The Smith case (for description see page 55), is specially adapted for rapid reconnaissance, topographic, and geologic work.

Transit or Wye level. Needed only in special cases, as detailed survey of an oil field, where greater accuracy is required than can be secured with hand level.

Minor instruments. The geologist should be supplied with a good pocket lense, several 4-inch celluloid or horn protractors, a 50 or 100-foot steel or linen tape, a zigzag jointed 5-foot rule, a tally register, a set of colored pencils, and a supply of 5H–8H drawing pencils.

Notebooks. A variety of notebooks are suited for field use, and the kind to be used will depend on individual preference and

Fig. 3.—Instrument belt.

the character of the work. The paper should be of good quality, sufficiently tough to stand hard usage, and with a surface suitable for both ink and pencil. For many purposes accurate quadrille ruling is essential, and convenient scales for both written and platted notes are five or six lines to the inch. For very detailed plats on large scale, as for mine notes, a convenient ruling is in inches and tenths.

The size of the notebook is a matter of individual preference, but experience has shown that a page about 5×7 inches is adapted to most purposes. For profile notes, described on page 61, a book 8×10 inches is somewhat more convenient, although the smaller page may be used nearly as well.

When observations on a number of different subjects are to be recorded, as is generally the case in areal work, a loose-leaf notebook is recommended. This permits the classification and assembling of notes relating to a single subject or a single area, whether made by one or several persons. It is also recommended for the geologist who visits a number of widely separated localities in the course of a single season. The outfit adopted by the U. S. Geological Survey consists of fillers containing forty-eight leaves, 5×7 inches, quadrille ruled on one side to sixths. They are bound in cheap press-board covers, and perforated for removal of leaves. Suitable punched holes at the top of the books permit the filing of the leaves in Twinlock binders.

Stationery box. Each party should be provided with a suitable box for carrying stationery, maps, notebooks, and instruments. A small steamer trunk with trays specially arranged for the purpose is most convenient.

Personal outfit. Conditions under which field work is to be carried on will necessarily determine the personal outfit with which the field man must provide himself. He will naturally consult his own taste in matters of dress, but certain considerations should be kept in mind.

(*a*) The bulk and weight of the outfit should be kept as low as possible. The allowable limit will be determined by the form of transportation. It should be lowest where there is to be much travel by stage and private conveyance or by pack train, and may be higher where work is done from a few hotels or from a camp provided with wagon transportation.

(*b*) Neatness in dress, so far as is compatible with the nature of the work, is strongly urged on field men. This can best be secured by having clothing specially designed for field work. Khaki has proved highly satisfactory under a variety of conditions, and samples of garments made from this material and suited for field use may be inspected in the office and ordered

from the maker at reasonable prices. It should be remembered that a survey is judged generally throughout the country by its field representatives, and in personal appearance as well as in other ways they should do it credit.

(*c*) Special attention should be given to shoes, since the conditions of a man's feet will materially affect the amount of work he will accomplish. Bedding will not generally be furnished, and the man who expects to live in camp should supply his own. Wool blankets of good quality are most satisfactory and economical, and in malarial regions a mosquito bar should always be used. Folding camp cots should be provided; also canvas bed covers.

(*d*) The chief, or some member of each party, should provide himself with a small supply of simple medicines, bandages, etc., and with directions for rendering first aid to the injured. This is especially important where the field work is remote from physicians and druggists. The outfit should include a hypodermic syringe and a supply of potassium permanganate for regions infested with poisonous snakes.

Camp subsistence. In some regions it is necessary, and in others desirable, to work with a camp outfit. The character of the outfit must be varied to meet the conditions, particularly the size of party, means of transportation, and character of work. It should contain the essentials for efficiency and comfort. Unnecessary hardship should be avoided as much as unnecessary luxury, for both lower efficiency.

Economy in the purchase and use of supplies is expected, though the supply should be abundant and of good quality. The subjoined ration, prepared primarily for the Alaskan parties of the U. S. Geological Survey, has been used for a number of years and found both abundant and well balanced. It will be found useful in ordering supplies, particularly when transportation is by packing, and therefore limited. The amounts of some articles will, of course, be reduced if fresh meat, eggs, and vegetables can be bought in the country, and also if transportation permits the carrying of canned vegetables, fruit, and milk.

UNIT RATION

[Pounds]

Flour or hard tack	1.000	
Cereals	.179	
Beans	.143	
Rice	.085	
Evaporated potatoes	.161	
Pea sausage	.032	
Evaporated soup vegetables	.018	
		1.618
Bacon	.716	
Butter	.140	
Dried beef	.027	
Crystallized eggs	.030	
Beef-tea capsules	.002	
		.915
Sugar	.251	
Tea	.036	
Coffee	.054	
Chocolate	018	
		.359
Onions	.0054	
Lime juice	.0008	
Vinegar	.0018	
Evaporated fruit	.2230	
		.231
Salt	.053	
Baking powder	.029	
		.082
Pepper	.002	
Mustard	.0004	
Celery salt	.0004	
Cinnamon	.0004	
Ginger	.0004	
Curry	.0004	
		.004
		3.209

It is often desirable to know in advance the amount of feed which will be required by stock, and the following ration may be used as a basis for estimates:

UNIT RATION FOR STOCK

[Pounds]

	Oats *or*	Corn.	Hay.
Heavy horses	12	15	18
Light horses	10	12	14
Mules	8	8	12

Discipline. In the conduct of a party in camp the chief should insist on punctuality, order, and neatness. With increase in the size of a party a proper amount of discipline becomes absolutely essential to efficiency. He should also insist on a proper regard for health on the part of each member of his party. Well-prepared food, protection from flies and mosquitoes, and care in respect to drinking water are prime essentials for health, and too much care cannot be exercised in these particulars. Camp sites should be carefully selected and the tents should be arranged in a definite order and not at random.

FIELD OBSERVATIONS

Essential qualities. Field observations should be *thorough, accurate, systematic,* and *comprehensive.* On the degree in which these qualities are realized will depend the value of the conclusions embodied in the resulting report, and hence the scientific standing of the geologist and his value to the organization employing him. No geologist achieves perfection in this particular, but nothing short of perfection should be the aim.

Thoroughness demands and involves willingness to perform the necessary labor required to get into close contact with the phenomena to be observed. It often entails foot work and climbing where the temptation is strong to use the glasses. It requires the same alertness at the end of a long day as at its beginning. The field geologist should always bear in mind the fact that he will probably never again see the particular locality he is studying, and should therefore aim to make his observations so thorough that he will never again need to see it.

Accuracy involves exact location by close watch of the map, constant appeal to measurement, minute examination, and a full record, for no matter how vividly observations seem fixed in the memory at the time, they will certainly fade and become so confused with others that their value will be reduced to zero or less.

System is easy for some and difficult for others, but can be cultivated with advantage by all. To assist in its cultivation is the object of the schedules appended to this volume.

Comprehensiveness comes with experience, together with an appreciation of the variety of phenomena to be observed and of their relations. There is no region so simple as to present only a single class of geologic phenomena and the geologist should observe all facts in some classes (determined by the main purpose of his work) and some facts in all classes. Even if his work is primarily economic, he should be thoroughly alive to the purely scientific problems presented by the region and can generally study one or more such problems without detriment but with probable advantage to his economic work.

Preliminary reconnaissance. On reaching the field, if the geologist is not already familiar with its general relations from previous work in the same or adjoining regions, he will find it highly profitable to spend the necessary time in making a preliminary reconnaissance. By this means he should be able to outline the problems to be investigated and to determine the logical order of procedure for their solution. A sufficiently definite idea of the physiography, stratigraphy, and structure should be acquired so that the field work may be planned to proceed from the simple and evident to the complex and obscure. Such a reconnaissance should always precede the study of economic problems and should generally cover a much larger area than will subsequently be worked in detail. The geologist should seek an early opportunity to become acquainted with the best-informed and most representative mining men of the district under examination, since much valuable information, such as drill records, mine maps, etc., obtainable in no other way, can often be procured from them. To secure their confidence and coöperation is therefore important.

Work of assistants. The responsibility for both quantity and quality of work accomplished by a party rests with the chief. He should see that assistants work to the best advantage, and no assistant should be permitted to carry on independent work until his reliability and capacity have been thoroughly tested. The work of assistants should be so arranged that the chief will have opportunity to check their results at frequent intervals. This inspection should be actual, and not merely perfunctory, and should extend to notebooks, maps, specimen labels, etc. It

is highly important, both for the chief and the assistant, that there should be full discussion of the problems under investigation during the progress of the work.

ESTIMATES OF DISTANCE, ETC.

It is not always practicable or necessary to make actual measurements of distances, dimensions, or angles. In many cases the measurements cannot be made by reason of inaccessibility, and in others the degree of accuracy required is not such as to justify the expenditure of time involved. It becomes necessary then to substitute estimates, and their accuracy depends in part on natural aptitude, but chiefly on training. The field geologist should therefore train his eye and judgment so as to attain the highest possible degree of accuracy. It is well to form the habit of making estimates before measuring distances or angles, for comparison with results of the measurement. Only by so verifying estimates can the desired degree of accuracy be attained.

Large distances and altitudes can be estimated best by applying some unit of measurement. Thus by repeated trials a horizontal distance of 100 or 1000 feet should be estimated within a small percentage of error, and these distances may be used as units for estimating the greater distance. In the same way 6 or 12 feet of altitude is easy of estimate and may be used as a measure in determining the height of a cliff or steep slope. The 45° angle can, with practice, be determined almost as accurately with the eye alone as with an ordinary clinometer, and by subdivision any other vertical angle can be obtained.

HORIZONTAL MEASUREMENTS

The necessity for determining horizontal distances with reasonable accuracy is of constant occurrence and a variety of methods may be employed, depending on the conditions present and the degree of accuracy required. These methods, named in the order of frequency with which they will be employed, are (*a*) pacing, (*b*) revolutions of a wheel, (*c*) tape, and (*d*) stadia.

Pacing. Every field geologist should be able to measure distances by pacing, with an average error not greater than 2 per cent on level ground and not greater than 10 per cent on the roughest ground and steep slopes. The length of the pace should be accurately determined under a variety of conditions. The accuracy is increased by making the pacing step slightly longer than the ordinary walking step. The separate steps may be counted, in which case some form of tally register should be used, or preferably only each fourth step should be counted, giving a four-step unit. This is conveniently done by naming a digit in the thousands, hundreds, tens, and units place for the four steps constituting the unit. Thus the first pace will be 0-0-0-1, the second 0-0-0-2, the tenth 0-0-1-0, etc. After a little practice the count becomes subconscious and distracts the attention only slightly from other things.

Distances may also be measured with a fair degree of accuracy, if the ground is not too rough, by counting a horse's steps. The length of the pace should be determined for each animal before it is used as a unit of distance.

Revolutions of a wheel. Where measurements are to be made on a road and a buggy or buckboard is available, there is great economy in the use of the circumference of a wheel as the unit. The actual revolutions may be counted, a piece of cloth or brush being tied to one of the spokes as a marker, or an odometer may be used. These instruments are, however, generally unreliable, and may introduce large errors into the measurement. If an odometer is used it is preferable to select one which records the actual revolutions of the wheel rather than one reading directly to miles and fractions of a mile. In fact, for traverse work the latter type is practically useless, as the smallest fraction to which it can be read is beyond the allowable limit of error in such work.

In making a traverse with wheel measurements the scale used for plotting on the plane table or notebook should be such that an even number of revolutions is represented by a unit division of the inch, so that it will not be necessary to reduce the revolutions to feet before plotting.

Tape line. The field outfit should always contain a 50 or 100-foot tape, preferably steel, for use in measuring short dis-

tances where a high degree of accuracy is required. It is especially useful in measuring sections for obtaining thickness where the conditions do not permit the use of a wheel. Two men are required for its use and a tally register is desirable.

Stadia. Where lines are to be run without reference to roads, so that a wheel cannot be used, and where a higher degree of accuracy is required than can be obtained by pacing, the stadia method may be employed. Any instrument carrying a telescope and vertical circle may be used for this purpose, as a transit or telescopic alidade. To the reticule of the telescope are added two or more fixed horizontal wires placed at certain distances apart. A rod subdivided to suit the interval between the wires and painted in distinct colors forms part of the outfit. When the rod is set up at a distance from the telescope, that distance is ascertained from the number of subdivisions included between the wires of the telescope, the value of each division of the rod being known. In measuring distance on slopes correction must be made to reduce the reading to horizontal distance.

In case it becomes necessary for the geologist to use the stadia, he should thoroughly familiarize himself with its construction and the precautions and corrections involved.

ANGULAR MEASUREMENTS

In all regions except those in which the bedding planes are approximately horizontal, or in which only massive crystalline rocks occur, determinations of strike and dip must be made upon practically every outcrop. This involves the measurement of vertical angles, which may be done with a clinometer (a convenient form of plumb line), or with spirit level and vertical circle (Abney hand level or Brunton compass). Less frequently, angular measurements are required for the determination of land slopes or heights of inaccessible objects.

In determining dip angles the edge of the clinometer may be placed directly upon the sloping surface to be determined, but care must be exercised that the part of the surface selected actually represents the average slope of the beds, and that the

measurement of the angle is not influenced by local irregularities. Also, to obtain the correct dip the edge of the clinometer must be placed on a line exactly at right angles to the *strike*—the intersection of a horizontal plane with the inclined bedding plane or other surface. Where the exposure is such as to permit it, better results can be secured by sighting to the edge of the beds across the edge of the clinometer at such a distance that several feet will be covered and the average dip obtained. Care must be taken to have the eye as near as possible in the extension of the plane whose inclination is being measured, and to sight on a horizontal line.

Land slopes may be measured with a clinometer when they can be seen in profile, but elsewhere by means of a vertical circle, approximately with the Abney level or Brunton compass, and accurately with a transit or telescopic alidade.

VERTICAL MEASUREMENTS

The means employed for determining differences in elevation will be varied according to the conditions and degree of accuracy required. The instruments most used are (*a*) the aneroid, (*b*) the hand level, (*c*) the wye level, and (*d*) the telescope with vertical circle.

Aneroid. The ease with which the aneroid is carried and read makes it an exceedingly useful instrument in geologic field work. The limitations to which it is subject should, however, always be kept in mind. Since the determination of difference in elevation depends on differences of atmospheric pressure, the apparent difference between two points may be increased or decreased by changes in the general barometric pressure of the region taking place during the interval between the taking of the observations. The time interval between readings should therefore be as short as practicable. The aneroid should be used differentially only, and its readings should be checked by reference to known elevations whenever opportunity is afforded during the day as well as at the beginning and end of each day's work. Whenever checked by comparison with a known elevation the movable

circular scale should be turned so that the needle is opposite the correct point on the scale. The elevations should then be read direct from the scale in feet. If no check can be made for several hours, and if, when checked, the reading is found to be too high or low by more than a contour interval, the error may be distributed backward over the readings in proportion to the intervals of time between them, or, in case of a traverse, in proportion to the distance.

The uncertainty of the aneroid is greatly increased in unsettled weather, when barometric changes are rapid, and it is practically useless immediately before and after a thunderstorm.

On account of the delicate mechanism employed to magnify the slight expansion and contraction of the vacuum box and transmit it to the index needle aneroids are easily injured and must be protected from any sudden jar. They should be carried preferably in a closely fitting vest or shirt pocket, secured by a string, or in a case fastened by a close loop to the belt. They should never be carried by a strap over the shoulder—particularly on horseback—or loose in the coat pocket or collecting bag.

Hand level. Small differences of elevation which must be determined with considerable accuracy, as for obtaining thickness of beds, should generally be measured with some form of hand level. The Locke level is simplest in construction and most convenient to carry, and will serve ordinary purposes. The Abney level is likewise serviceable and may be used also to measure vertical angles. The Brunton compass may be used as a hand level, and if so used it will be unnecessary to carry a level in addition. In case a large amount of hand leveling is to be done, and the slopes are gentle, as on roads, the telescopic hand level is the best instrument to use.

The distance to the observer's eye above the ground should be determined to the nearest tenth of a foot. The best results are obtained on a moderately steep slope, so that the point determined on a level with the eye may not be too distant for easy identification when it is reached. On a very steep slope elevations may be determined with a fair degree of accuracy without an instrument, by estimating the horizontal point with the eye.

It sometimes becomes necessary to determine differences in

elevation where the ordinary method of using the hand level by sighting to the ground ahead is not applicable, as where the slope is gentle and covered with tall grass or brush so that the ground cannot be seen. Under such circumstances the assistance of a rodman is necessary. If sights of 200 feet or more are to be taken the hand level may be fastened across the end of a stick of convenient length—about 5 feet—and so held much steadier than without such a support. The Abney level is supplied with a socket for use with a Jacobstaff. A level rod may be made from a light, straight pole, 10 feet long, the end of a rule held against it being used as a target. Fore sights and back sights are made and recorded as when using the wye level, but the height of the instrument is constant.

Wye level. It sometimes becomes necessary to determine elevations more accurately than can be done by the methods described above. This is the case, for example, where the minor structures are being worked out in an oil field and the elevation of outcrops or of well heads must be known within a foot or two. Under such conditions flying levels are run with a wye level from the nearest bench mark. This work is slow and expensive and should therefore be confined to the absolutely necessary locations and used only where there is a good topographic base available. A special notebook adapted for both level and geologic notes has been designed by M. J. Munn, and should be used where much of this work is done.

Telescope with vertical circle. In case the stadia method is employed for measuring distances, either with a transit or with a telescopic alidade, elevations will at the same time be obtained by means of vertical angles. Tables for obtaining elevations from stadia readings are given in "Geographic Tables and Formulas," published by the U. S. Geological Survey. The use of this instrument in geologic work, however, will be exceptional, and before attempting to use it the geologist should acquire experience under a competent instructor.

DETERMINATION OF THICKNESS OF BEDS

In the study of areal, stratigraphic, and structural geology, the thickness of beds must be determined at many points. The character of the topography and of the outcrops, and inclination of the beds, will determine the method employed.

The simplest case is where the beds are approximately horizontal and the slopes are steep. Under such conditions it is necessary only to measure the vertical distances between upper and lower limits of the stratigraphic units by aneroid, hand level, or wye level, depending on the degree of accuracy required. If the slope on which the section is made is very steep—30° or more—dips of 3° or less may be neglected.

If the beds dip, three factors must be determined—(*a*) dip angle, (*b*) slope angle, and (*c*) distance across the beds normal to the strike; and three cases occur—(*a*) with surface horizontal, (*b*) with surface sloping and beds dipping into the slope, and (*c*) with surface sloping and beds dipping with the slope. These three cases are shown in Fig. 4, from which it is seen that—

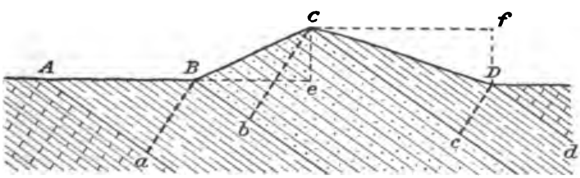

FIG. 4.—Diagram illustrating determination of thickness of beds by trigonometric method.

(*a*) Thickness of beds A to $B = aB = AB \times \sin BAa$.

(*b*) Thickness of beds B to $C = bC = BC \times \sin (CBe + eBb)$.

(*c*) Thickness of beds C to $D = cD = CD \times \sin (fCc - fCD)$.

The dip angle ($BAa = eBb = fCc$) is measured directly with the clinometer; the slope angles (CBe and fCD) are either measured

directly or obtained from the difference in elevation, which is the slope distance into the sine of the slope angle, i.e.,

$$\operatorname{Sin} CBe = \frac{Ce}{BC};$$

$$\operatorname{Sin} fCD = \frac{fD}{CD}.$$

These results may be expressed in the following rules:

(1) Where the surface is horizontal, the thickness equals the distance across the dipping beds multiplied by the sine of the dip angle. (2) Where the surface slopes and beds dip into the slope the thickness equals the distance across the beds multiplied by the sine of the sum of dip and slope angles. (3) Where the surface slopes and beds dip with the slope the thickness equals the distance across the beds multiplied by the sine of the difference of dip and slope angles.

To facilitate calculations a table of natural sines and tangents is given on page 37.

With increasing dip the horizontal measurement becomes relatively more important than the vertical, and where the dip becomes approximately 90° the difference in elevation between limits of the beds may be neglected and the true thickness will be represented by the horizontal distance measured at right angles to the strike of the beds.

A convenient method of determining the thickness of beds, without calculation, when the angle of dip and horizontal distance across the outcrop normal to the strike are known, is by the use of the diagram shown in Fig. 5. The horizontal rulings correspond to degrees. Any convenient scale may be adopted for the spaces between vertical rulings, as 1, 10, 50, or 100 feet. To determine the thickness of beds, find the horizontal line corresponding to the dip angle and follow it to the right for a distance corresponding to the measured distance across the outcrop on the scale selected. If this distance coincides with a curved line the latter is followed to the top of the diagram, where the thickness is determined directly by the distance between it and the left margin, the same scale being used. If the point falls between

two curved lines, the measurement is made to a point at the top of the diagram having the same relation to these lines.

A convenient method for the direct measurement of thickness

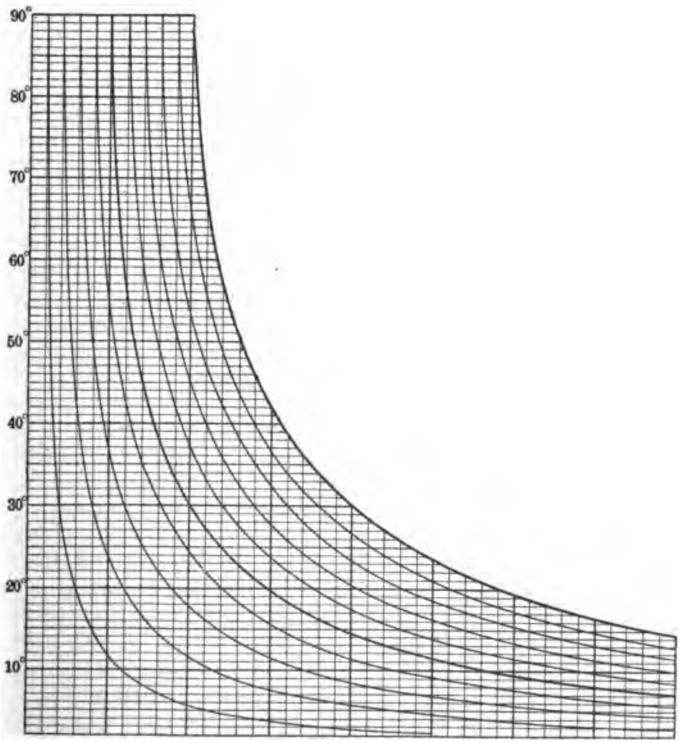

Fig. 5.—Diagram for use in determination of thickness of beds by graphic method.

in making detailed sections, particularly on steep slopes or with steeply dipping beds and where exposures are nearly continuous, is as follows. To the upper end of a rod of convenient length—5 feet is about right for a man of ordinary height—is fastened

a short arm to form a right-angled T. A zigzag jointed 5-foot rule may be used instead of the rod. In addition to the rod either (*a*) a hinged clinometer with level on one arm, or (*b*) an Abney level, or (*c*) a Brunton compass is used. The dip of the beds is determined, and if a clinometer is used the arms are opened so that the angle between them is equal to the dip angle. If then, the lower limb of the clinometer is held firmly on the top of the T rod and the rod is inclined until the upper limb is horizontal, the lower limb will be in the plane of bedding projected upward toward the observer. By sighting down this limb the bed in whose plane it lies is determined and the beds between this plane and the foot of the rod have a thickness equal to its length. The foot of the rod is now moved up to this bed and again brought into position so that the upper limb of the clinometer is horizontal and the rod is at right angles to the bedding, and a new point is obtained by sighting down the lower limb. Count is kept of the unit thicknesses and the total thickness between determined limits is obtained with no calculation except a multiplication of the length of the rod into the number of sights taken. The method is very similar to the use of the hand level for obtaining elevations, and becomes identical with it when the dip becomes zero.

When the Abney level or the Brunton compass is used the method is the same, except that the vernier arm carrying the level is set at a point on the divided circle corresponding to the dip angle.

Where surface exposures are nearly or quite continuous, so that it is not necessary to follow stream channels, and where dips are steep and variable, sections should be measured as nearly as possible at right angles to the strike. In order to get the best exposures it is generally necessary to make occasional offsets along the strike, following some easily identifiable bed or contact. Measurements along the strike need not be made with the same degree of accuracy as those normal to the strike. The notes of such a traverse may conveniently be kept in tabular form, a page of the notebook being ruled into columns for (1) number of the station, (2) character of rocks, (3) distance (measured on the slope), (4) slope angle (U when the slope is up in the direc-

tion of traverse and D when it is down), (5) altitude (or elevation with reference to any assumed datum), (6) dip angle (F when the dip is in the direction of the traverse, and B when the reverse), (7) strike, and (8) thickness. All columns except the last should be filled as the traverse proceeds, and where direct measurements can be made the thickness should be recorded also. Columns 3 to 6 contain the necessary data for computing thicknesses by the methods given above, if they cannot be measured directly.

In case it is necessary to make surface measurements diagonally across the strike, the distance normal to the strike is determined by the solution of a right-angled triangle, the line traversed being the hypothenuse (h) and the angle which this line makes with the strike being an adjacent angle (c). The side (B) opposite this known angle will be the distance on the slope normal to the strike—that is,

$$B = \frac{h}{\sin c}.$$

In making sections of steeply inclined and poorly exposed beds, the observed dips at the nearest exposures often show wide variation. A convenient method of obtaining approximate thicknesses under such conditions is as follows: Measure horizontal distances as nearly as possible at right angles to the strike, locating and measuring as many dips as possible. Construct a normal profile to scale and plot upon it all dips projected in their proper horizontal relations, as in Fig. 6. Extend the dips in straight lines above and below the profile. At the intersection of each dip line with the surface profile draw a line at right angles and extend it until it intersects the dip lines on either side. The thickness of the beds between any two observed exposures, as A and B, will be equal to one-half the sum of the lines intersected between the dip lines above and below the profile—that is,

$$\text{Thickness of beds } A \text{ to } B = \frac{Ab' + aB}{2}.$$

$$\text{Thickness of beds } C \text{ to } D = \frac{Cd' + cD}{2}, \text{ etc.}$$

These values can be scaled off directly from the diagram. The construction is based on the assumption that the dip varies uniformly from *A* to *B*, *C* to *D*, etc., which may or may not be the case. Moreover, the results are too large if the observed dips are at different elevations and converge downward, and they are too small if they diverge. Thus in the section represented by Fig. 3 the thicknesses will be approximately correct from *A* to *E*, too small from *E* to *F*, and too large from *F* to *G*. The method is applicable therefore only where the profile is

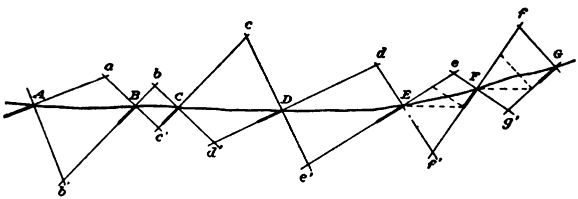

Fig. 6.—Diagram illustrating determination of thickness of beds by construction method.

approximately horizontal and should be employed only where the exposures are not sufficient for more accurate measurement.

DETERMINATION OF DEPTH OF BEDS

It is frequently necessary to determine in the field the depth of a particular bed or horizon at a distance from its outcrop, or to determine the distance from the outcrop at which a coal bed or oil sand reaches a given depth. The problem may be solved by graphic or trigonometric methods.

The graphic method involves the construction of a section at right angles to the strike. Dips are plotted on the profile drawn to scale and showing the thicknesses of intervening beds as determined by the methods given in paragraphs 1 to 8, above. The depth of a bed at any point, or the distance from the outcrop at which any bed reaches a given depth, can then be scaled off directly from the section.

By the trigonometric method three cases occur—(1) where the surface below which the depth is to be determined is horizontal, (2) where the surface slopes and the beds dip into the slope, and (3) where the surface slopes and the beds dip with the slope. The three cases are shown in Fig. 7, from which it is seen that—

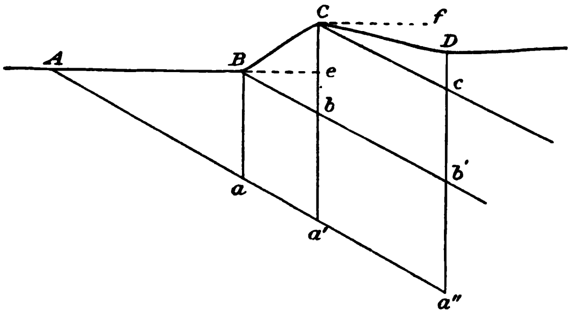

FIG 7.—Diagram illustrating determination of depth of beds by trigonometric method.

(1) Depth of bed Aa at $B = Ba = AB \times \tan BAa$.

(2) Depth of bed Bb at $C = Cb = \dfrac{BC \times \sin CBb}{\cos eBb}$.

(3) Depth of bed Cc at $D = Dc = \dfrac{CD \times \sin DCc}{\cos fCc}$,

and depth of bed Aa'' at $D = Da'' = Ba + Cb + Dc$.

In this figure AB, BC, and CD are the surface distances normal to the strike of the beds; BAa, eBb, and fCc are the dip angles; CBb is the sum, and DCc is the difference of dip and slope angles.

For convenience in determinations where the surface is approximately horizontal, a table giving depths of a bed for various angles of dip and distances from outcrop is inserted on page 38. Where the slope is gentle and great accuracy is not required,

this table may be used, by adding to the depths given the difference in elevation between the outcrop and the point at which the depth is desired—the difference in elevation being positive when this point is higher than the outcrop and negative when it is lower. The errors will generally be well within the limits of accuracy of measurement, and the formulæ given above need not be employed except with steep slopes.

DETERMINATION OF FAULTS

Where exposures are sufficiently abundant the facts necessary for the determination of the direction and extent of a displacement, particularly if it is relatively small in amount, may be observed directly. As a rule, however, the dip of the fault plane and the direction and amount of displacement must be inferred from a number of observations at different localities. Field observations should be made with especial care and completeness in the vicinity of faults, for it is here that the unexpected is always apt to occur.

Dip of fault plane. It often happens that the contact of rocks on opposite sides of a fault plane cannot be seen at any point, although the fault may be traced for many miles. To afford data for determination of the dip, as many points as possible on the fault should be accurately located both horizontally and vertically. The points should be selected so that the horizontal distances will be as small, and the vertical as large, as possible. Three points properly selected and accurately located will give better results than a larger number less carefully chosen and determined. The best locations are at the bottom of a valley transverse to the fault and on the hills on either side. The three points fix the position of the fault plane, and its dip or the angle it makes with the horizontal may be determined by construction or trigonometric methods. The trigonometric method involves the solution of a number of triangles and the extraction of square roots. Its practical application, therefore, necessitates the use of logarithmic tables, which are not generally accessible in the field. The method by construction is relatively simple and

requires only a protractor, dividers, and scale. This method is illustrated in Fig. 8, and is as follows:

Let the three points in the fault plane be *A*, *B*, and *C*. Let *C* be the lowest and *B* the highest, the differences in elevation having been determined. The horizontal or slope distances from *C* to *A* and *B*, and the azimuth of the lines connecting them, have also been determined. Lay off with the protractor the lines *CA* and *CB*, in proper azimuth on the scale adopted. If these lines represent slope distances, project the points *A* and *B* upon the horizontal plane passing through *C*, as follows:

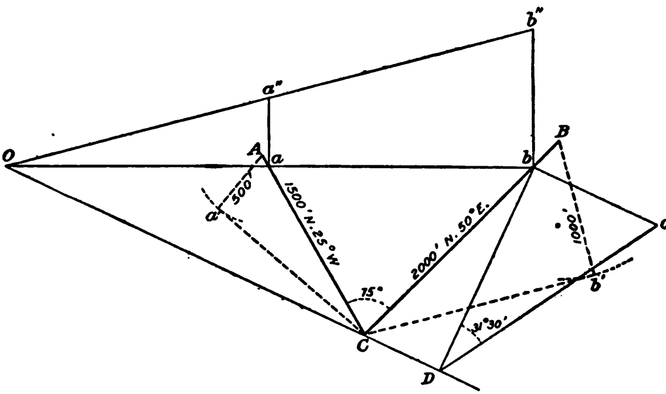

FIG. 8.—Diagram illustrating determination of dip of fault plane.

Construct a right triangle (*BCb′*) with *CB* as the hypothenuse and the difference in elevation between *C* and *B* as the perpendicular. Lay off on *CB* a distance equal to the base of this right triangle—that is, *Cb*=*Cb′*. Determine the point *a* on *CA* in like manner. Draw a line through *a* and *b* and extend it beyond *a*. The triangle *aCb* is the horizontal projection of the portion of the inclined plane included by the lines connecting *A*, *B*, and C. If the distances between *C* and *A* and *B* are horizontal distances this projection is not necessary, since the triangle can be drawn at once—in the horizontal plane—and the line completing the triangle will be drawn through *A* and *B*.

At a and b erect perpendiculars equal respectively to Aa' and Bb', and draw a line through their extremities to its intersection with the line ba extended at O. This point of intersection will be in the horizontal plane and also in the inclined plane. Since C also is in the same horizontal plane and in the inclined plane, a line connecting O and C will be the intersection of these two planes, and hence the *strike* line. From the horizontal projection of either of the points, as b, let fall a perpendicular to D on this strike line OC extended. From b draw bd perpendicular to bD and equal to Bb', the difference in elevation between C and B. Connect its extremity with D and the angle bDd will be the angle sought, the inclination of the fault plane to the horizontal.

Unless the field measurements have been made with exceptional accuracy the error in the above solution will come well within the limit of error of observation.

This method is of course applicable in the determination of strike and dip of any inclined plane in which the relative position of three points is known. Thus it will be found useful in determining the strike and dip of a bed which is intersected by drill holes, or which, from the nature of its exposures, does not admit of direct measurement.

Angle of intersection with oblique vertical plane. It frequently becomes necessary to determine the angle of intersection of a fault (or other inclined plane) with a vertical plane oblique to the strike of the fault.

The trigonometric solution may be used when tables of natural or logarithmic functions are at hand. Let m be the angle of dip of the inclined plane and n the angle between the strike of the inclined plane and the vertical plane. To find x, the angle which the line of intersection of the two planes makes with the horizontal,

$$\tan x = \tan m \sin n.$$

The problem may be solved by construction as follows: Let AK, Fig. 9, be the azimuth of the vertical plane; draw AL so that the angle $KAL = n =$ the angle made by the strike of the inclined plane and the azimuth of the v^rtical plane. Take any

point (C) on AL and erect a perpendicular CB. With CB as a base construct a right triangle with the angle $BCD=m=$the angle of dip of the inclined plane. Draw $BD'=BD$ and at right angles to AB. Connect A and D'. The angle $BAD'=x$ will be the angle sought.

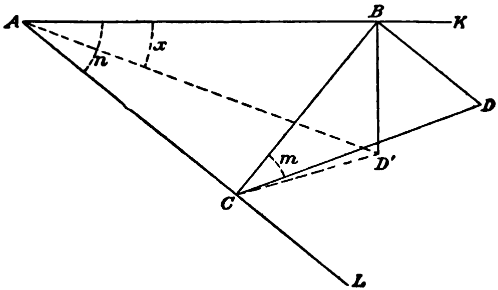

FIG. 9.—Diagram illustrating determination of angle of intersection of fault plane with vertical plane oblique to strike of fault.

Percent and angular inclination. The attitude of slightly inclined bedding planes or other surfaces is generally expressed by engineers in percentages, and it is therefore frequently neces-

TABLE 1.—CONVERSION OF PERCENT GRADE TO ANGULAR INCLINATION

Percent Grade.	Angular Inclination.	Percent Grade.	Angular Inclination.	Percent Grade.	Angular Inclination.
1.	35′	7.00	4°	13.00	7° 25′
1.50	52′	7.50	4° 15′	14.00	8°
1.75	1°	8.00	4° 35′	15.00	8° 30′
2.00	1° 10′	8.50	4° 50′	15.85	9°
2.50	1° 25′	8.75	5°	16.00	9° 5′
3.00	1° 45′	9.00	5° 10′	17.00	9° 40′
3.50	2°	9.50	5° 25′	17.65	10°
4.00	2° 15′	10.00	5° 45′	18.00	10° 15′
4.50	2° 35′	10.50	6°	19.00	10° 45′
5.00	2° 50′	11.00	6° 15′	19.45	11°
5.25	3°	11.50	6° 35′	20.00	11° 20′
5.50	3° 10′	12.00	6° 50′	21.00	11° 50′
6.00	3° 25′	12.25	7°	21.25	12°
6.50	3° 45′	12.50	7° 10′		

sary to convert such percentages into their equivalent angles. It is also at times desired to convert angular inclination into the equivalent percentage. This conversion involves the use of a table of natural tangents more extended than that given on page 42, and the above table of equivalents is therefore inserted. The angles are given only to the nearest five minutes, which is sufficient for geologic purposes, and is nearer than the angles can be plotted with an ordinary protractor.

Form of outcrop. The line drawn on the map to represent a formation boundary is the trace of two intersecting surfaces—the land surface and the surface separating the overlying and underlying formations. Since both are irregularly warped surfaces their intersection will be a complicated trace, and unless careful consideration is given to the geometric relations involved, the location of the line is apt to be inconsistent with the geologic structure. If it were possible or practicable to actually trace on the ground all lines which will be shown on the map, their location would be a simple matter, but the nature of exposures generally prevents such continuous tracing, and even where this is not the case the expenditure involved would be excessive and prohibitory. In practice, therefore, the location is determined of as many points as possible under the limitations of time and expense, and the line is drawn upon the map between these determined points so as to be consistent with the form of the two intersecting surfaces.

It is assumed that the land surface will be accurately represented by contours; the form of a line marking the intersection of a land surface so represented and any geological surface, as a bedding plane, fault plane, unconformity, eruptive contact, etc., may be considered under three cases: (1) in which the geologic plane is approximately horizontal; (2) in which it is approximately vertical, and (3) in which its inclination varies anywhere between 0° and 90°.

(1) It is evident that the intersection of a horizontal geologic plane with any land surface will coincide with an interpolated land surface contour, since by definition contours are simply the traces of intersections of the land surface with equidistant imaginary horizontal planes.

A boundary between horizontal formations will therefore be drawn between located points in such a manner as not to cross a contour line. The drawing of such lines, particularly if a large number of points are located, is a rigid check on the accuracy of the contouring and will generally necessitate more or less revision of the latter.

(2) It is equally evident that the intersection of a vertical geologic plane with a land surface is not influenced by the inequalities of the latter, and therefore has no definite relation to the surface contours. Hence a boundary between vertical formations will be drawn between located points by straight lines or confluent curves, regardless of contours.

(3) Between the two extremes, horizontal and vertical dips, an infinite variety of relations occur between the intersection and the contour lines. Two general cases may be discriminated; (*a*) where the geologic plane dips into a sloping land surface, and (*b*) where it dips with the land surface. The two cases are illustrated by the formation boundaries, (*a*) on the face, and (*b*) on the back of a monoclinal ridge, as shown in Fig. 10, in which the contour interval is 100 feet and the distance from A to B is one mile.

Let it be assumed that a section has been made across the ridge from A to B and the points M, N, O, and P on the formation boundaries accurately located; also that the strike and dip of the beds have been determined. The problem is to determine the location of the boundaries on the map with reference to the contours when continued on either side of the section.

Points on these lines may be determined in the following manner. Construct the profile AB to scale. The distance between the horizontal ruled lines is equal to the contour interval, 100 feet, and the profile is constructed by projecting the points of intersection of the profile AB and the various contours. Project upon this profile the points M. N, O, and P, and draw the lines $M'm'$, $N'n'$, etc., the angles corresponding to the determined dip of the beds. In the same manner construct the profiles $A'B'$, and $A''B''$. The point m', at which the dip line $M'm'$ intersects the profile $A'B'$ is projected upon the section line $A'B'$, and fixes the point on the map at which the boundary crosses the bot-

tom of the ravine. Between *M′* and *m′* the dip line crosses the horizontal ruled line corresponding to the 700-foot contour.

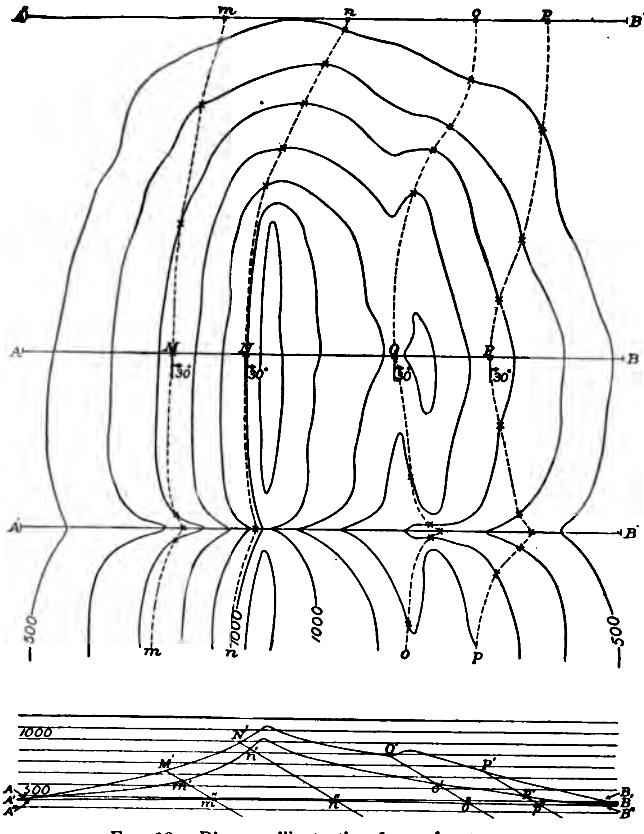

FIG. 10.—Diagram illustrating form of outcrop.

This point projected upon the map gives the several points at which the boundary *mm* crosses this contour, and in a similar manner the points at which it crosses the 600 and 500 contours

are obtained. Connecting the points thus located on the map the correct position of the boundary is fixed.

The dip line $N'n'$ does not cross a horizontal line between N' and n', hence the boundary *nn* remains between the 900 and 1000-foot contours in crossing the ravine $A'B'$.

In the same way points are located on *oo* and *pp*. The dip line $O'o'$ crosses the two horizontal lines between O' and o', hence the boundary crosses two contours between the point O and the bottom of the ravine in which the section $A'B'$ is located. The points at which it crosses the contours are determined as above, by projecting the intersections of the dip line and the horizontal ruled lines upon the corresponding contours.

From an inspection of the diagram it will be observed (1) that wherever the boundary lines cross surface depressions they bend in the direction of the dip, (2) that where the bedding planes dip *into* the slope (*mm* and *nn*, case (*a*) above), the boundary lines bend in the same direction as the contours, but less acutely; (3) that where the bedding planes dip *with* the slope (*oo* and *pp*, case (*b*) above), the boundary lines bend in the opposite direction from the contours, and the deviation from a straight line increases as the dip decreases, (4) that the width of outcrop of a formation which occurs on a slope is less than the outcrop of the same formation on a level surface if the beds dip into the slope, and greater if they dip with the slope.

TABLES AND FORMULAS

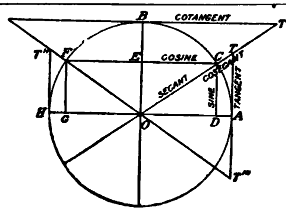

FIG. 11.—Diagram illustrating circular functions.

SOLUTION OF TRIANGLES

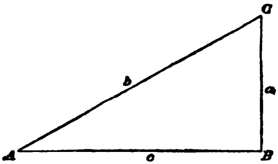

FIG. 12.—Right triangle.

Sin $A=\frac{a}{b}$. cos $A=\frac{c}{b}$. tan $A=\frac{a}{c}$.

$C=90°-A$. $b=\sqrt{a^2+c^2}$. $c=\sqrt{(b+a)(b-a)}$.

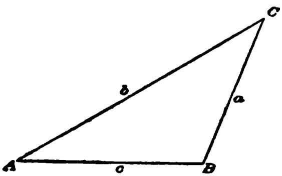

FIG. 13.—Oblique triangle.

Given.	Required.	Formula.
A, B, a	b	$b=\frac{a \sin B}{\sin A}$.
A, a, b	B	$\sin B=\frac{b \sin A}{a}$.
C, a, b	B	$\tan B=\frac{b \sin C}{a-b \cos C}$.
a, b, c	A	If $s=\frac{1}{2}(a+b+c)$. $\sin \frac{1}{2}A=\sqrt{\frac{(s-b)(s-c)}{bc}}$. or $\cos \frac{1}{2}A=\sqrt{\frac{s(s-a)}{bc}}$.
a, b, c	Area	Area$=\sqrt{s(s-a)(s-b)(s-c)}$
A, B, c	Area	Area$=\frac{1}{2}bc \sin A$.

CIRCLES

Circumference$=2\pi R$. Area$=\pi R^2$. $\pi=3.1416$

TABLE 2.—NATURAL CIRCULAR FUNCTIONS.

°	Sine.	Tang.	Cosine.	Cotang.	°
0	0.0000	0.0000	1.0000	Infin.	90
1	.0175	.0175	.9999	57.2900	89
2	.0349	.0349	.9994	28.6363	88
3	.0523	.0524	.9986	19.0811	87
4	.0698	.0699	.9976	14.3007	86
5	.0872	.0875	.9962	11.4301	85
6	.1045	.1051	.9945	9.5144	84
7	.1219	.1228	.9926	8.1444	83
8	.1392	.1405	.9903	7.1154	82
9	.1564	.1584	.9877	6.3138	81
10	.1737	.1763	.9848	5.6713	80
11	.1908	.1944	.9816	5.1446	79
12	.2079	.2126	.9782	4.7046	78
13	.2250	.2309	.9744	4.3315	77
14	.2419	.2493	.9703	4.0108	76
15	.2588	.2680	.9659	3.7321	75
16	.2756	.2868	.9613	3.4874	74
17	.2924	.3057	.9563	3.2709	73
18	.3090	.3249	.9511	3.0777	72
19	.3256	.3443	.9455	2.9042	71
20	.3420	.3640	.9397	2.7475	70
21	.3584	.3839	.9336	2.6051	69
22	.3746	.4040	.9272	2.4751	68
23	.3907	.4245	.9205	2.3559	67
24	.4067	.4452	.9136	2.2460	66
25	.4226	.4663	.9063	2.1445	65
26	.4384	.4877	.8988	2.0503	64
27	.4540	.5095	.8910	1.9626	63
28	.4695	.5317	.8830	1.8807	62
29	.4848	.5543	.8746	1.8041	61
30	.5000	.5774	.8660	1.7321	60
31	.5150	.6009	.8572	1.6643	59
32	.5300	.6249	.8480	1.6003	58
33	.5446	.6494	.8387	1.5399	57
34	.5592	.6745	.8290	1.4826	56
35	.5736	.7002	.8192	1.4282	55
36	.5878	.7265	.8090	1.3764	54
37	.6018	.7536	.7986	1.3270	53
38	.6157	.7813	.7880	1.2799	52
39	.6293	.8098	.7772	1.2349	51
40	.6428	.8391	.7660	1.1918	50
41	.6560	.8693	.7547	1.1504	49
42	.6691	.9004	.7431	1.1106	48
43	.6820	.9325	.7314	1.0724	47
44	.6947	.9657	.7193	1.0355	46
45	.7071	1.0000	.7071	1.0000	45
°	Cosine.	Cotang.	Sine.	Tang.	°

TABLE 3.—DEPTH TO A STRATUM BELOW HORIZONTAL SURFACE FOR VARIOUS DISTANCES AND DIPS

Dip Angle Degrees.	Feet.						¼ mile (1320 feet).	½ mile (2640 feet).	¾ mile (3960 feet).	1 mile (5280 feet).
	100.	200.	300.	400.	500.	1000.				
1	1.75	3.50	5.25	7.00	8.75	17.5	23.04	46.08	69.12	92.16
2	3.49	6.98	10.47	13.96	17.45	34.9	46.09	92.18	138.3	184.4
3	5.24	10.48	15.72	20.96	26.20	52.4	69.18	138.4	207.5	276.7
4	6.99	13.98	20.97	27.96	34.95	69.9	92.30	184.6	276.9	369.2
5	8.75	17.50	26.25	35.00	43.75	87.5	115.5	230.5	346.5	461.9
6	10.51	21.02	31.53	42.04	52.55	105.1	138.7	277.4	416.1	555.0
7	12.28	24.56	36.84	49.12	61.40	122.8	162.1	324.2	486.3	648.3
8	14.05	28.10	42.15	56.20	70.20	140.5	185.5	371.0	556.5	742.0
9	15.84	31.68	47.52	63.36	79.20	158.4	209.1	418.2	627.3	836.3
10	17.63	35.26	52.89	70.52	88.15	176.3	232.8	465.6	698.4	931.0
11	19.44	38.88	58.32	77.76	97.20	194.4	256.6	513.2	769.8	1026
12	21.26	42.52	63.78	85.04	106.30	212.6	280.6	561.2	841.8	1123
13	23.09	46.18	69.27	92.36	115.45	230.9	304.7	609.4	914.1	1219
14	24.93	49.86	74.79	99.72	124.65	249.3	329.1	658.2	987.3	1316
15	26.80	53.60	80.40	107.20	134.00	268.0	353.7	707.4	1060	1415
16	28.68	57.36	86.04	114.72	143.40	286.8	378.5	757.0	1136	1514
17	30.57	61.14	91.71	122.28	152.85	305.7	403.6	807.2	1211	1614
18	32.49	64.98	97.47	129.96	162.45	324.9	428.9	857.8	1287	1716
19	34.43	68.86	103.29	137.72	172.15	344.3	454.3	908.6	1363	1817
20	36.40	72.80	109.20	145.60	182.00	364.0	480.4	960.8	1411	1923
21	38.39	76.78	115.17	153.56	191.95	383.9	506.7	1012	1520	2027
22	40.40	80.80	121.20	161.60	202.00	404.0	533.3	1067	1600	2133
23	42.45	84.90	127.35	169.80	212.25	424.5	560.3	1121	1681	2241
24	44.52	89.04	133.56	178.08	222.60	445.2	587.7	1175	1763	2351
25	46.63	93.26	139.89	186.52	233.15	466.3	615.5	1231	1847	2462
26	48.77	97.54	146.31	195.08	243.85	487.7	643.7	1287	1931	2575
27	50.95	101.90	152.85	203.80	254.75	509.5	672.6	1345	2018	2690
28	53.17	106.34	159.51	212.68	265.85	531.7	701.8	1404	2105	2807
29	55.43	110.86	166.29	221.72	277.15	554.3	731.7	1463	2195	2927
30	57.74	115.48	173.22	230.96	288.70	577.4	762.1	1524	2286	3048

WRITTEN NOTES

All notes must be legible, not only to the person who makes them, but to anyone else, and that without undue effort in deciphering them. A reasonably clear handwriting is therefore essential and no field geologist can afford to use an illegible scrawl. If abbreviations are used they must be unambiguous, and such as will be readily understood without a key—e.g., sandstone, ss; limestone, li or ls; quartz, qtz; quartzite, qzt; etc.

Notes must be definitely localized and connected with a map. The exact system of reference employed is not important, provided it is simple, unambiguous, and consistently used. The locality at which an observation is made, or a specimen taken, should be marked on the map by a small cross or dot, or in case of a section by a line connecting two crosses or dots, with a reference which may be (*a*) number and page of notebook, (*b*) a date with letter indicating separate notes for that day (8–7–13–E), or (*c*) any combination of numbers and letters which will serve to connect the point on the map with the written note and enable either to be found readily from the other.

If the geology is so complex that a large number of observations must be made within a small area and the reference numbers would become confused, some system of coördinates may be used, viz.:

(*a*) The atlas sheet is dissected on meridians and parallels—10′ each way if the scale is 1 : 125,000 and 5′ if it is 1 : 62,500; the sections are numbered and pasted on a page of a notebook with quadrille ruling to sixths of an inch; the rulings about the margin of the map are continued across it both vertically and horizontally; letters are placed across the top and numbers down the side. A dot is placed on the map at the point of observation, and the notebook reference will consist of an abbreviation of the quadrangle name, the number of the section of the atlas sheet, and a coördinate letter and number—e.g., Ro–3–B13. If several points fall in the same square they may be distinguished by letters indicating the quarter, as NW., NE., etc.

(*b*) The atlas sheet is dissected and pasted in the notebook as above. Each section is subdivided on meridians and parallels into 25 quadrangular areas, 1′ or 2′ each way, depending on the scale, and each of these into 9 quadrangular areas. The last

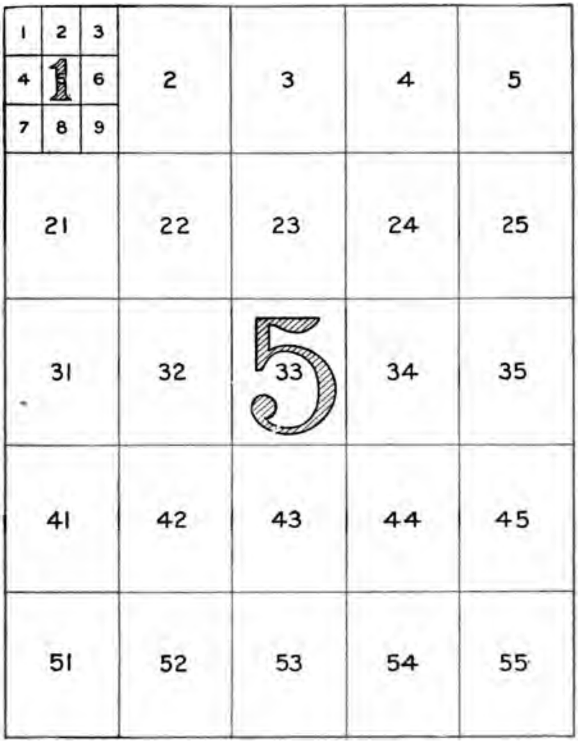

FIG. 14.—Diagram illustrating subdivision of map for reference numbers.

subdivision need not actually be made on the map, as the position of a point within the 1′ or 2′ areas can be estimated. The method of subdivision and numbering is shown on the accompanying diagram (Fig. 14). With this system a notebook refer-

ence would consist of an abbreviation of the quadrangle name and the numbers of the successively smaller subdivisions—e.g., Ro2-35-6.

In case the writing of specimen numbers would confuse the map if placed on its face a convenient method of location is to make a pin hole through the map and write the number on the back of the notebook page on which it is mounted.

When a topographic map is not available the descriptions of the locality should be sufficiently exact and complete to enable another observer to find the locality on the ground without difficulty. This of course makes it necessary for the observer to know exactly where he is when he makes the observation. If he does not know, his first duty is to find out.

Distances, thicknesses, and dimensions should be expressed in definite units derived from actual measurements or estimates—and the notes should state which—and not by means of indefinite or relative expressions as a "short distance," "a considerable thickness," etc. Estimates should be accepted only where the object is inaccessible or where an error of ten per cent or more is permissible.

Written notes should be dated and signed and should contain some information as to the conditions under which the observations were made—e.g., from camp, with its location; on foot; from public stage; etc.

Notes should be carefully classified under prominent headings to facilitate indexing. Clearness and ease of reference, classification, and indexing are more important than economy of paper. Headings may be added later, to save time in the field, but the habit of making them on the spot is a good one. If a loose-leaf notebook is used, only one subject should be placed on a page, so that the leaves may be assembled and classified under various subjects and localities. In this case the classification need not be fixed at once and is always subject to change.

The record of facts actually observed should be kept separate and distinct from conclusions based on inference, hypotheses, and theories, which, however, should not be omitted but written down as they occur in the field. They can easily be eliminated later when—as will often be the case—they are proved incorrect.

The clear-cut statement of a hypothesis often initiates the search for additional data which may prove or disprove the hypothesis.

MAP NOTES.

For field notes it is generally desirable to use a map enlarged by photography to at least twice the scale of the engraved atlas sheet. If necessary for clearness the drainage may be inked in blue. If specified on the requisition the photographs can be toned to give brown instead of black lines, which adds materially to the legibility of the map and the added data. The paper used should be of the best quality as to toughness and texture for taking ink. Only waterproof inks should be used on maps either in the field or in the office.

Boundaries of cartographic units must be placed on a map in the field. If by reason of inadequate exposures a boundary cannot be accurately located on the ground, no amount of study in the office will increase the probability of correct location and the benefit of many significant facts of soil, topography, etc., will be lost. If a guess is the best that can be done, the best place to make the guess is on the ground. *Observed* and *inferred* boundaries should be discriminated—as by solid and dotted lines—and a special symbol should be used for various classes—e.g., comformable contacts, sedimentary unconformities, faults, intrusive contacts, etc. The map should show the exact point at which the observation was made. It frequently happens that the cartographic units which are to appear on the published map are not determined until the work is well advanced or until office determinations have been made. It is highly desirable, therefore, to locate and place on the map in the field not only those boundaries which will certainly be used, but also those which may possibly be used.

Structural data should be placed on the map in the field by means of suitable symbols showing dip and strike of beds, structure axes, dip of faults, etc. These symbols should indicate as nearly as possible the exact locality at which the observation was made. They should show angles of dip by figures, and

should be sufficiently abundant to enable structure sections to be drawn wherever desirable.

Lithologic and stratigraphic data may generally be placed on the map in the field by means of abbreviations. These, however, should always be supplemented by written notes and the exact locality at which detailed lithologic observations are made or sections measured and described should be indicated on the map by a reference number or letter connecting it directly with the record in the notebook. By the use of a hard pencil and with careful writing a surprisingly large amount of information can in this way be placed directly on the map.

Localities at which collections of rocks, minerals, fossils, etc., are made should be indicated on the map; also generally points from which photographs are taken, with the direction of view indicated.

Economic data, such as locations of mines, quarries gravel pits, undeveloped deposits, and prospect pits, should be placed directly on the map; also, unless the system is too extensive and complicated, mills, breakers, ore roads, etc.

Special care must be taken to secure neatness and accuracy in putting these data on the map. A soft or blunt pencil should never be used and unnecessary lines should not be drawn in advance of the determination of boundaries, or so that there will subsequently be an uncertainty of several hundred feet in location. The use of colored pencils for drawing boundaries is sufficient evidence of inaccuracy to completely condemn a piece of geologic work. All lines determined by each member of the party should be inked on his own map and the lines determined by other members of the party should be transferred to it in pencil.

In working an area for which there is a topographic map several copies should be kept in the stationery box and used for the compilation of various classes of data. This is especially necessary where there are several persons in the party. In case a photographic enlargement is used for field notes, these compilation sheets should be the regular engraved base. As the work progresses and tentative cartographic units are decided on, boundaries should be transferred to an undissected base map

in ink and the areas of the various units colored. Pencils may be used for this purpose, or, preferably, transparent Japanese water colors. The latter are recommended for field use on account of their convenience and the excellent results which they give. This map should always be brought up to date before moving camp or station.

There should be a route map showing, by means of different-colored inks, the exact route followed by each member of the party each day; also location of camps or other stopping places and route of camp outfit. This sheet may also be utilized as an index of collection and photograph localities. To another sheet should be transferred in ink all determined boundaries and the principal structural data. A third should show economic data, location of mines, quarries, mills, industrial railroads, tramways, etc. If many topographic corrections and additions are found necessary, they should be carefully plotted on a separate sheet, in ink, for transmission to the topographic branch.

While the geologist should carefully avoid a hypercritical attitude toward the topographic maps, he should note all essential omissions and errors and wherever practicable furnish data for making corrections. Changes in culture, particularly roads, bridges, railroads, etc., should be accurately noted. When an enlarged photograph is used in the field, allowance must be made for the difference in scale, particularly in criticizing contour generalizations. The map may be entirely adequate for the engraved scale and yet open to criticism if judged on an enlargement for which it was not drawn.

GRAPHIC NOTES

Sketches. As written notes are intended both to record facts and relations and to present a word picture of the things observed, they can generally be supplemented with great advantage by sketches and diagrams. A simple sketch is frequently the most satisfactory record of complex relations, particularly where the elements are on a small scale, so that their relations can be brought together in a single view. Such a sketch generally requires less

time than a complete written description and makes definite the relations which written notes can only vaguely express; moreover, its construction will frequently call attention to important points which might otherwise be overlooked. The habit of making numerous sketches is therefore one which every field geologist should acquire and constantly practice. It is not necessary that they should possess artistic merit, but merely that they should be clear and faithful to the facts. They are essential in connection with observations on ore deposits, details of contacts, unconformities, minor structures, etc. The broader relations of strutture to relief can also be brought out by sketches, but, unfortunately, more skill is required for this than the ordinary geologist possesses.

For geologic purposes sketches may be classed as *plane* or *perspective.* Plane sketches or diagrams are those in which relations of two dimensions only are represented. They are sketch maps, outlines, profiles, and sections. The method does not differ materially from topographic mapping. The outline or surface to be sketched is examined for salient points. The relations of these among themselves are noted to give control. Details are then filled in according to the complexity of the subject and the skill of the draftsman. In securing the control directions should be compared with the vertical or horizontal, and should be estimated or proportionately measured by scaling on a pencil held at arm's length. To fill in the work, the sketcher traverses or meanders the outlines with the eye and plots the traverse between control points by hand. The best practice is to keep the eye most of the time on the object and to train the hand to follow with only occasional guiding glances at the paper. The number of lines should be the least that will express the relations.

Perspective sketching is like plane sketching, except that the objects drawn must be projected into one plane from their relative positions in three dimensions. An imaginary surface is assumed (the ground glass of the visual camera, as it were), and the control and traversing are executed as if the objects were all seen through that surface and thus observed on it. In order to express greater or less distance, relative size, amount of detail, distinctness of line, density of shadow, etc., are considered.

Photographs. The use of the camera has become so common that it has to a large extent displaced sketching by geologists. While a photograph is valuable as a record of facts and relations, it should be remembered that the camera shows no discrimination and cannot select and separate the important from the unimportant. It is, therefore, unless conditions are exceptionally favorable, generally less satisfactory and convincing than a sketch. Moreover, it is a mistake to suppose that effective photography requires less skill than good sketching. The operator needs to know the limitations of his lens, his plate, and his subject in order to judge the value of a picture before taking it. For it is not enough to take a picture. There should be an obvious feature or features related to the object of study and of such a character as to be clearly recognized in the photograph. That which is plain to the narrow vision of well-directed observation may become an insignificant detail through a wide-angle lens. That which is distinct through differences of color may be obscure in colorless light and shadow. Thus photography requires care and judgment, and these qualities are the more important because every exposure entails future expense for developing, printing, cataloguing, and filing.

In the use of the camera in the field two purposes should be kept in mind—to secure (*a*) an accurate record of facts—in other words, graphic notes—and (*b*) material for illustration of reports. For the first purpose, since the photographs are primarily for the geologist himself, attention should be given to bringing out the particular facts and relations desired in order to supplement the written notes, and the photographs should in turn be supplemented by written notes and sketches. For the second purpose attention should also be given to "composition" and the possibilities of reproduction. The reader who sees the result may be entirely unfamiliar with the region described, and the view should so far as possible set the main features clearly before him.

A critical examination of the U. S. Geological Survey photographs for the selection of views illustrating geologic and physiographic types has brought out the fact that in most cases not sufficient care has been exercised in selecting the point of view.

This care should be proportionate to the interest of the subject. Important adjuncts, the explanatory settings of a picture, are often lost through being too near to the object and desirable detail through being too far away from it. If a convertible lens is used, the combination should be employed which is best adapted to secure a complete view with the most detail.

TRAVERSE NOTES

Exact location, both horizontal and vertical, is essential in nearly all forms of geologic field work. If this is not furnished by a topographic map it must be supplied by the geologist himself through some form of traverse. Even the best topographic maps will show some areas in which location is impossible without traverse. The method of making a traverse should therefore be familiar to all field geologists.

Notebook traverse. The general direction of the proposed traverse having been determined, select a point on the edge of the notebook page so that this direction will pass through its center. If the point of starting is identifiable on the map, indicate it there by a suitable reference number; take a compass sight to some object in the direction to be traversed and lay this down on the notebook page with a protractor; measure the distance by pacing or otherwise to the object sighted, and lay off this distance on the scale selected; from this new point take a second compass sight, lay it off with the protractor, and proceed as before. Relief adjacent to the line of traverse should be indicated by sketch contours with sufficient care to give a general idea of its character, and both drainage and culture should be indicated. These features should be given with sufficient accuracy to check the topographic map, or in the absence of a map to supply its place. The larger scale permits fuller geologic notes to be written on a notebook traverse than on a topographic map. The scale selected should be such as to give a simple relation between the pace or other unit of distance and the notebook ruilng—a convenient scale is 40 four-step units to one square (one-sixth or one-fifth inch). The scale used should be noted

on each page containing the whole or part of a traverse, and particularly the equivalent in feet and inches of the unit employed.

The method and results of a notebook traverse are shown in Fig. 15, which represents a single day's work and covers about 6 square miles of moderately complicated geology, with 11.5 miles of traverse. The geologic mapping is sufficiently close for publication on the 1 : 125000 scale but not on the 1 : 62500, for which at least 50 per cent more locations on formation boundaries should have been made.

The traverse was started at Rock Spring P. O., where a line by *HBG* was started eastward on the same day. This point was located near the upper right-hand corner of the notebook page, since the area to be covered lay to the southwest. At the end of the second course a sight was taken to a limestone quarry and the distance to it paced. A description of the quarry, arranged under the headings given in Schedule 8, was written in the notebook H^6 and given a designation consisting of the date and a letter—8/30A. Returning to the main road the line was continued southward to a point where a trail started up the end of the ridge to the west. The traverse was carried along this trail following the crest of the ridge to its highest point, and continued down the point to the contact of a formation known to extend several miles to the northwest. Written notes were made at B. and C. and a detailed section was measured at D. Returning to the high point the traverse was carried along the ridge forming the southwestern side of a pitching syncline, to the main valley road where it failed to close by about 370 feet. This illustrates a common tendency to overestimate paced distances in ascending and underestimate them in descending a slope. The main line was then continued south to Alexander Gap, tieing at that point with *HBG* line of the previous day, and at Colvin Station with *RD* line also of the previous day. From Alexander Gap a circuit was made to the west with several spur lines to determine the structure and distribution of the formations within a small area of exceptional complexity. This circuit tied with the main line at Colvin with an error of 350 feet. Finally, from Colvin a line was run across the strike about midway between the two circuits. Sketch contours were drawn only to show

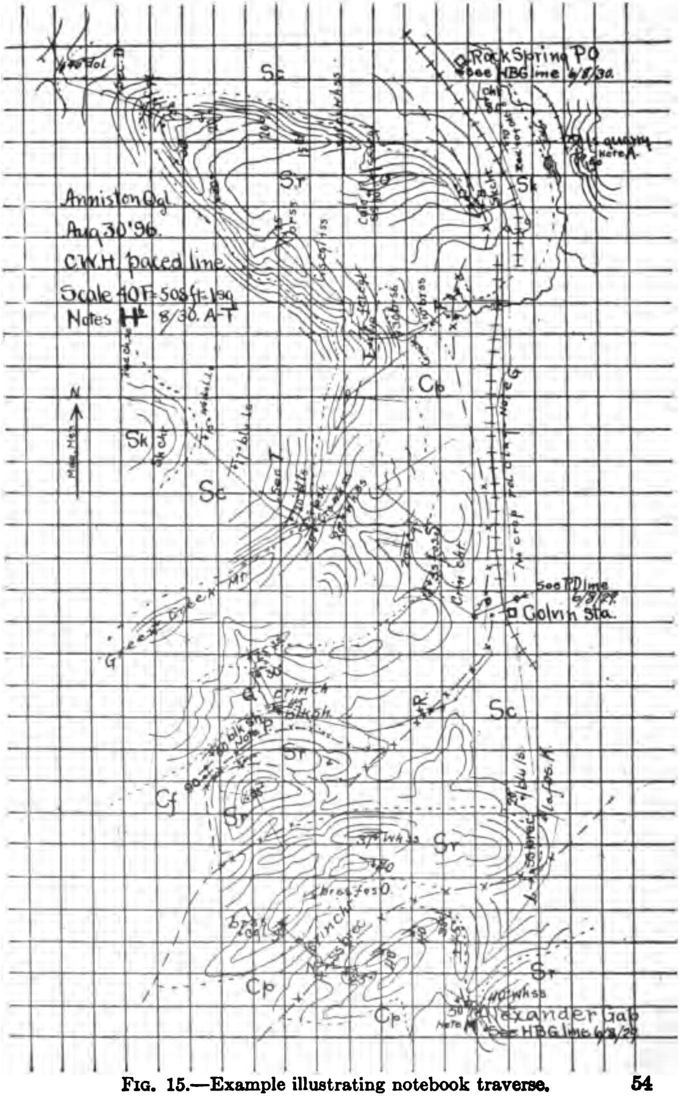

Fig. 15.—Example illustrating notebook traverse. 54

form and relative elevation of surface with no attempt to determine absolute altitudes. All formation boundaries and faults were drawn as determined on the ground and sketched in between observed points in conformity with the topography.

Sketching-case traverse. For rapid traverses where greater accuracy is required than the notebook method permits, the use of a sketching case may be found advantageous. This instrument, as modified by Glenn S. Smith, is shown in Fig. 16. It consists essentially of a small board 8 by 12 inches in size provided with a roller at each end carrying a long strip of transparent paper. A compass box carrying a 3-inch floating card graduated to 360° and furnished with rifle sights is attached to one corner. Under the paper is a circular plate which can be rotated and moved laterally across the board, and on which is attached a card 6 inches in diameter containing a combined protractor and scale. The protractor is graduated to degrees and numbered from 1 to 360. A radius extends from the center to each degree and these are divided into equal parts by a series of concentric circles, so that any radius may be used as a scale. Protractor cards are furnished, suitably divided for any scale desired, as 1 to 45,000, 1 to 90,000, or tenths of an inch.

To use the sketching case, attach the paper to the rollers, winding all, except enough for fastening, on the upper roller. Determine the general direction of the traverse to be made, revolve the protractor plate until the degree corresponding to this direction comes opposite the index line over the clamp screw, and clamp the plate in place. Draw a line on the paper through the zero and 180° points; this line will be the magnetic meridian. Move the protractor plate so that its center is near the middle of the paper; the station occupied is indicated by a point over the center of the protractor; sight to the next station to be occupied and draw a line on the radius corresponding to the compass reading; measure the distance to this station and plot it by means of the scale on this radius; move the paper down until the point indicating the second station is opposite the center of the protractor, and move the protractor plate sideways until its center coincides with this point; sight to the next station and to any points to be intersected, and draw lines on the radii

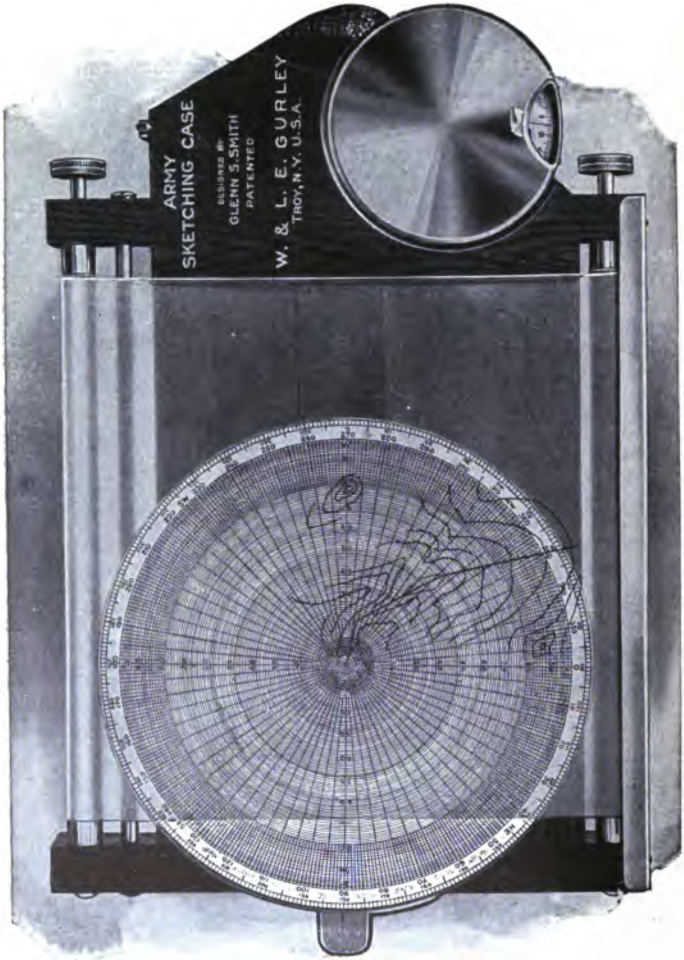

Fig. 16.—Topographic sketching case.

corresponding to the compass readings. Relief, culture, and geologic data are recorded exactly as in a notebook or plane-table traverse.

Map traverse. In case an enlarged photograph of the base map is used in the field it is frequently desirable to secure accurate location by means of a traverse plotted directly on the map. If the magnetic declination is more than 3° the magnetic meridians should be drawn on the map and used instead of the true meridians for plotting compass directions. More care is required in scaling distances than in making a notebook traverse, on account of the smaller scale, but a decided advantage is gained in that the notes need not be transferred.

PLANE-TABLE NOTES

While the plane table is primarily a topographic instrument, it is under some circumstances utilized in geologic work. In the absence of a topographic map, or where topographic and geologic work are being carried on at the same time, the plane-table method with or without supplementary notebook traverses may be adopted. It is much more accurate than the notebook traverse and hence should be used for purposes of control even where the greater part of the work is done by more rapid but less accurate methods. It is practically indispensable in case it becomes necessary to make a detailed topographic map of a small area—for example, a small mining district. In such a district, where the geologic structure is apt to be exceptionally complex and a high degree of accuracy is required, a plane table may be used with advantage, even with a good topographic map.

The geologist will rarely need to make use of the more elaborate forms of the instrument, such as the Johnson head and telescopic alidade. The traverse plane table with open-sight alidade, will answer all ordinary needs. This consists of a board about 15 inches square, into one edge of which is set a narrow box containing a compass needle. The table is supported by a light tripod and is leveled by means of the legs. A screw fastens the board to the tripod head and it is held in adjustment in azimuth by

friction. The table is oriented by means of the compass needle; that is, it is turned until the needle rests opposite the zero marks in the compass box and is thus always made parallel to its former positions, provided the magnetic declination remains constant. The alidade consists of a graduated brass ruler, 6 to 12 inches long, with folding sights. Ordinary drawing paper backed with cloth is used and is attached to the board by thumb tacks.

In making a topographic map or a combined topographic and geologic map the following procedure is employed. The instrument is set up at the initial point, roughly leveled, and oriented. A point is marked on the paper to represent the initial station, the edge of the alidade is placed on it and pointed to the object selected as the second station, and a line is drawn in that direction. Sights are also made and lines drawn in the direction of any prominent objects which it is desired to locate, such as rock outcrops, hilltops, buildings, etc. The instrument is then taken to the station sighted, the distance being measured and noted, and is either set up at this second station or moved to a third station, from which the second is visible. The distance from the first to the second station is laid off on the line connecting the two, on the scale selected. This gives the point on the paper representing the position of the second station and may be occupied by setting up the instrument as at the initial point; or if the instrument is moved to the third station, after orienting, the edge of the alidade is placed on the second station point and sighted to that point. The line drawn will then connect the second and third station points, and the position of the third is determined by laying off the measured distance between them. From each station occupied sights are made to objects to be located and intersections of the lines drawn from the various stations will give their locations. At least three intersections should be secured on each object. Aneroid elevation should be noted at each station and at intermediate points when necessary. Drainage and culture should be sketched and all prominent geologic features located while the traverse is being run. The contours may be sketched at the same time, or this may be done subsequently by the same man, or one more experienced, after the traversing is completed. The geologic boundaries and other

necessary geologic data may be also placed on the map during the traversing or after its completion.

Supplementary notebook traverses in the area covered by the plane-table sheet should be transferred to that sheet in the field, in order to bring together geologic observations in their proper relations during the progress of the work.

The traverse method in plane-table work will be the one commonly employed by the geologist, but under certain conditions it may be desirable to make all locations by intersection. Such conditions are afforded by an unforested region of considerable relief, particularly one in which there is much local magnetic attraction, as is usually the case where coal beds have been burned on the outcrop.

A base line is measured from which suitable points may be sighted for expansion by the development of a series of triangles. The base should be measured by tape or by stadia, using sights not more than 500 feet, on as level ground as possible, and so located that the ends are intervisible. Special care should be exercised in determining both the length and direction of the base line and both foresights and backsights used to obviate error due to possible local attraction. The length of the base will depend on local conditions, but one mile will generally be ample. The points selected for expansion of the base should be so located as to give sufficiently wide angles for accurate intersections.

Having established a sufficient number of control points within the area to be mapped, station locations are obtained by setting up the plane table, and drawing backsights from several control points. The compass needle may ordinarily be used for orientation, but if there is local attraction it will at once be recognized by failure to obtain a good intersection on the first orientation, and the location must be found by the "three-point" method. The following graphic solution of the problem is most convenient for field use.* Orient the table as nearly as possible, and draw lines from three located points which will intersect to form a "triangle of error." Now rotate the table slightly and draw lines from the same three points. A new triangle of error will

* For a full explanation of the solution see Geo. B. Chittenden, 9th Ann. Rept., Hayden Survey, 1875, p. 365.

be formed similar to the first. Connect similar angles of these two triangles and the lines extended will intersect in a common point, which will be the correct position of the station. The table can now be correctly oriented by placing the edge of the alidade upon this point and one of the located points and rotating the table until they fall in line. This method is most readily applied when the station is (*a*) within the triangle formed by the three located points, or (*b*) outside of this triangle but within the circle drawn through these points. The position of the triangles of error in these two cases is shown in Fig. 17.

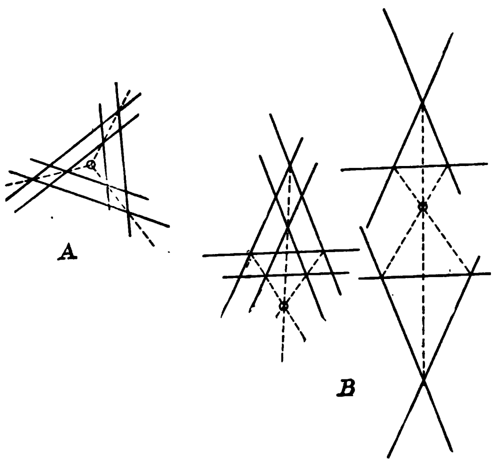

FIG. 17.—Diagram illustrating triangle of error.

In case a small area is being worked in detail, as a mining district, and a good topographic map is available, the plane table may be used with advantage for securing exact location on the map. For this purpose the map should be enlarged to a convenient scale by photographing if necessary, and a mounted copy fastened to the board with thumb tacks, the magnetic meridian being placed exactly parallel to the edge of the board containing the compass box. If the angle of magnetic declination is large,

it is necessary to place the sheet askew upon the board, a condition which reduces the size of the sheet that can be used and is otherwise objectionable. To obviate this difficulty the map is tacked on the board with the true meridian parallel to its edge. (*a*) The compass box, instead of being fastened rigidly to the board, is hinged at one end and the other end is supported by a graduated arm which passes under the board and on which it may be swung out and clamped at an angle equal to the local magnetic declination; or (*b*) the magnetic meridian is marked on the map and the board is oriented by placing the edge of a box compass against this line and turning the board until the needle stands at the north and south points on the circle. The orientation is effected more accurately and conveniently by the use of a special alidade devised by L. C. Graton and differing from the ordinary alidade in having a compass box, similar to the one ordinarily attached to the plane table, set on the base, the sights folding down on one side of the box. The edge of this alidade is placed on the line marking the magnetic meridian and the board is turned until the needle rests at the zero points. The alidade is then used as the ordinary instrument. The advantages of this modification are that greater accuracy is secured by having a longer edge for adjustment to the meridian line than when the compass is used, and that time is saved by having one less instrument to handle. After the board is oriented two or more points which lie within the mapped area, and which can be identified on the map are selected. Sights are taken to these points and the intersection of the lines fixes the point at which the instrument is set up.

PROFILE NOTES

A convenient method of recording observations under special conditions has been devised by M. R. Campbell and used extensively in the Eastern and Central coal fields. The conditions for its use are (*a*) approximately horizontal bedding—dips less than 5°—and (*b*) a good topographic base map with numerous determined elevations. It is particularly useful where the strata con-

sist of similar beds frequently repeated and poor in fossils, so that the exact stratigraphic position of a particular bed cannot be determined by inspection alone, and where, in addition, the rocks are not well exposed. The method consists essentially in constructing a continuous sketch-profile section for all routes traversed, the geologic data being placed directly upon this profile by graphic conventions or, if written, referred to it.

A notebook having quadrille ruling to sixths of an inch is used. A convenient vertical scale is selected—say 120 feet to the inch, or 20 feet to each square of the ruled page. No attempt is made to preserve uniformity in horizontal scale.

The following is the procedure. Begin at a point certainly identifiable on the map, as a crossroads or stream crossing. Place a reference on the map consisting of the number of the notebook page used (numbers of left-hand pages are used for both left and right) and a letter indicating the number of the station—e.g., 6*a*. Place the same letter at a point on the left-hand margin of the page in such a position that the highest point on the profile drawn to the scale selected will come below the upper edge of the page. The altitude of the starting-point—determined directly from the map or from the aneroid previously set at the nearest bench mark—determines the position of the point between rulings and also the altitudes represented by the rulings adjacent, several of which should be marked on the margin of the page. For example, if the elevation of the starting point is 868 feet, the ruling below it will be marked 860, the one above 880, etc. Proceed from the starting point along any route which can be identified on the map as a road or trail to the first decided change in slope, noting elevations of outcrops and contacts and of the second station. Plot the profile to this point, using the vertical scale selected, and indicating by appropriate symbols and at their proper altitudes all exposures and contacts seen. Symbols for shale, sandstone, conglomerate, limestone, coal, etc., should be carefully selected and used consistently. Proceed to the next decided change in slope and plot the profile and outcrops as before. When a second point is reached which can be certainly identified on the map, place a new reference on the map at that point and a corresponding letter on the profile. In case the aneroid does

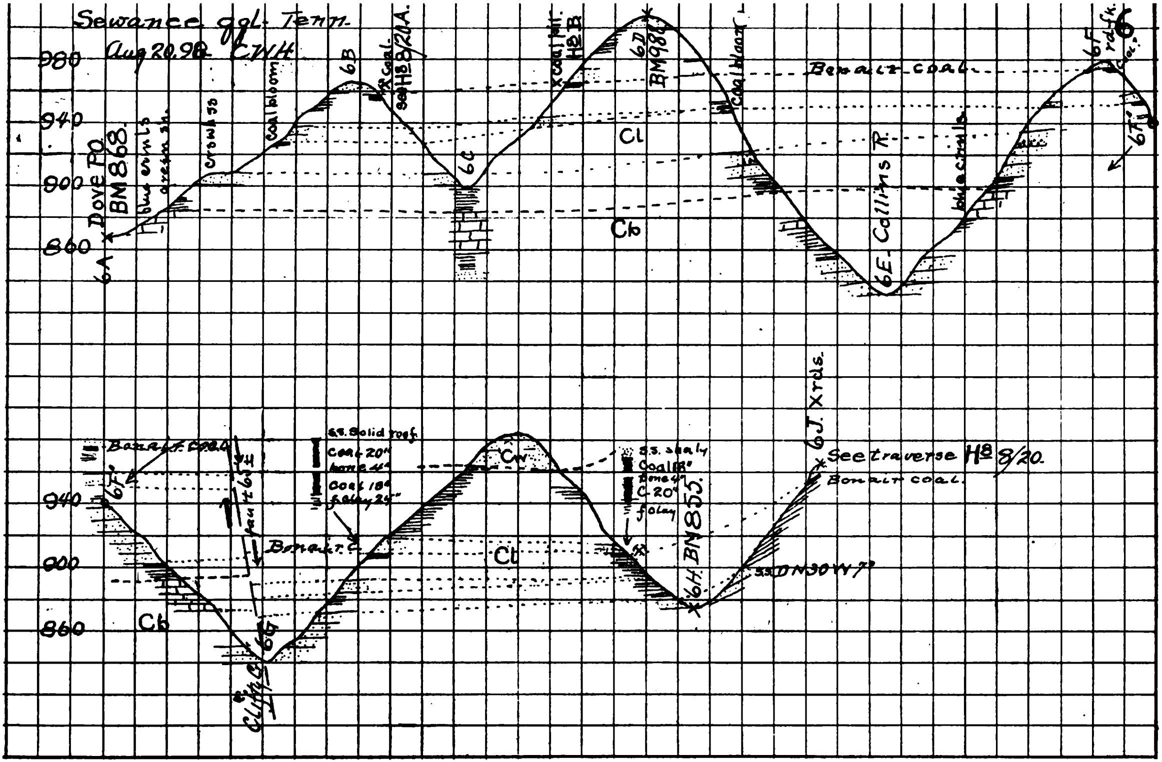

FIG. 18.—Example illustrating profile notes.

not give sufficiently accurate results it should be supplemented by the hand level.

As the work progresses, the positions of various outcrops of beds which have been recognized at several places should be connected, and these connecting lines will indicate the direction of dip and of structure axes, though of course on a very much exaggerated scale. They will also indicate the approximate position of important horizons, as formation boundaries and coal beds, which may be so nearly concealed that they would otherwise be overlooked.

As a final result the method yields a complete network of intersecting profiles which enable the geologist to identify with certainty particular beds or horizons which have not sufficiently well-marked characteristics for identification by ordinary means.

The profile notes require special treatment in the office to deduce from them the true structure, underground contours, and exact location of boundaries, but this matter need not be discussed here. In addition to the data shown graphically on the profile there should always be supplementary written notes, describing lithologic character, nature of contacts, economic materials, etc. These notes are placed on any unused portion of the page or on a separate page, and connected with the profile by reference numbers. At the same time that the profiles are being constructed, formation boundaries, so far as they can be determined, should be placed on the map as when other methods are used.

The results of the profile method are illustrated in Fig. 18.

LAND-CLASSIFICATION SURVEYS

In regions which have been subdivided by the public-land system but not surveyed topographically or, if surveyed, in which land lines are not accurately shown on the topographic map, it may be necessary to make a combined geologic and topographic survey—particularly for the purpose of classifying the public lands as mineral and non-mineral. In such surveys the one absolutely essential condition is that both topography and geology

shall be tied to the land lines and mapped in their proper relations to the land subdivisions. To comply with this essential condition a sufficiently large proportion of the land corners must be actually found to give the necessary control—to enable the geologist to say with assurance in what township, section, and forty any point on the ground is located. Such surveys, therefore, differ from the ordinary combined topographic and geologic surveys described on the foregoing pages in having a fixed horizontal control already established on the ground.

All available information which will be of assistance in locating corners and adding horizontal and vertical control should be in hand before beginning work on any township. Much of this information can often be procured by correspondence before taking the field and later supplemented by personal visits to local land offices, county surveyor's offices, etc. The most important is derived from (*a*) township plats and field notes of the original land surveys, from the General Land Office, also brief descriptions of corners from records of surveyors-general; (*b*) maps and profiles of surveys for railroads, reservoirs, canals, pipe lines, etc., obtained from the files of the Land Office and Reclamation Service, or from railroad engineers; (*c*) county road maps, town plats, claim maps, private ranch maps, etc., which can usually be obtained from the county surveyor's office.

After a Government corner on the township to be surveyed has been found and identified, additional corners sufficient to establish control must be found. The method of marking corners given in the General Land Office "Manual of Surveying," which can be secured from that office, should be thoroughly familiar to everyone working in a region of public-land surveys.

In a thinly settled region the best method of finding corners is by traversing the township and section lines. If accurate sights are taken with the compass on a Jacob's staff or with the plane-table alidade, and care is taken in pacing, the radius of the circle within which the next corner must be sought is so reduced that if a corner was ever established in a proper manner the chances of finding it are good. Other methods of locating the point on the ground where the corner ought to be found may be used, as by triangulation with plane table or by meander

traverse, but these require more skill than section-line traverses and should be used only in exceptionally rough country or where the corners are conspicuously marked. Valuable information relative to the status of land corners in a given district can frequently be obtained from county surveyors.

The greater part of the topographic sketching and determination of geologic boundaries and structure can be done from the traverses required in the location of corners, but additional locations of important topographic and geologic features should be made by traverse or intersection. Roads, trails, and streams can generally be sketched with sufficient accuracy from section lines, but if not, they should be traversed. It should be remembered that the unit of land classification is the sixteenth of a section—that is, a 40-acre tract; it will therefore generally be essential in coal-land surveys to traverse the principal coal outcrops and prospect them wherever necessary to determine their thickness.

Blank township plats should be used for all graphic notes, preferably those on the scale of two inches to the mile, though half of this scale may be used if the geologist possesses the necessary drafting skill. The plats may be folded for use in a notebook or fastened on a plane table. The blank plats are ruled to correspond to a theoretically perfect township, and do not provide for the irregularities made necessary by the adjustment of actual surveys along township exteriors and between surveys made at different times. These irregularities can be obtained from the original Land Office plats, a copy of which should be in hand, and should appear on the completed plat; otherwise both topography and geology will be distorted. Care should be exercised to see that the work done by different men is connected, any lack of perfect correspondence in topography or geology between townships or portions of townships being always adjusted before leaving the field.

As in other kinds of surveys, special conditions will be met that will require more refined methods than those outlined above, as the stadia for making horizontal locations and the level for vertical control. The work then becomes primarily topographic and need not be considered here.

In some cases it may be impossible to find any corners in one or several adjoining townships, either because they were not properly marked, or for other reasons. The lands in such townships cannot be finally classified until they have been resubdivided. While it may sometimes be necessary to continue work in them in order to trace formations, the necessity for subsequent adjustment of the geology and topography to the land lines should be kept in mind.

Each township plat as completed in the field should show (*a*) legal designation; (*b*) name of the person or persons who did the work, and the part for which each is responsible; (*c*) inclusive dates and number of days spent by each person; (*d*) magnetic declination to nearest degree; (*e*) by legend, all distinctive symbols used, contour interval, and geologic formations in proper sequence; (*f*) relief by means of contours; (*g*) drainage, perennial and intermittent, lakes, swamps, irrigation ditches, and playas; (*h*) culture—railroads, roads, trails, houses, etc.; (*i*) geologic boundaries, which must be put in carefully with hard pencil and then inked; (*j*) coal outcrops, shown by a continuous heavy inked line where seen, and by a broken line where inferred; (*k*) all found corners (by special symbol) and all lines traversed; (*l*) location of lines along which profiles were made; (*m*) reference numbers to notebook for indicating location of observations recorded in written notes, specimens, fossil localities, etc.

MINE SURVEYS

In the study of an ore deposit the first essential is to procure a map of the underground workings. If a mine map has been made, the officers of the company will nearly always permit the geologist to make a tracing. This may be done on tracing linen, but where the study is incident to other work and the geologist is not equipped with such drawing material, tissue paper may be used, or even, if this is not at hand, ordinary wrapping paper, the mine map being pinned below the paper and traced on a windowpane or showcase. It will frequently be convenient to reduce the mine maps by pantagraph or a slower method of squares.

If there is no map available the geologist should make a traverse survey on a suitable scale, say 50 or 100 feet to the inch. The ordinary notebook with coördinate ruling, spaced ten lines to the inch, is very convenient, and the method will be a modification of the notebook traverse already described. If there is a long, crooked adit driven through barren ground to the ore body it may not be necessary to survey all of it, but the survey should then be connected with the surface through some air shaft or other opening.

The Brunton compass is best adapted to underground work, but the Gurley or any other compass without a mirror may be used. Satisfactory results may be had when the compass is held in the hand, but a traverse plane table will be found useful in mines where there are not too many abandoned ladders to climb. It frequently happens that the geologist must explore a mine without an assistant or companion. In this case he will find it convenient to save the ends of his candles to use as station signals.

In making a traverse survey of a mine, the geologist enters the tunnel or other opening and paces as far as he can go and still see daylight. He then sights back to daylight and with a protractor plots his course in a notebook. He leaves a lighted candle at this point and then paces as far as he can go and still see the candle. The second course is plotted in the notebook, joining the course from daylight to the first candle. This is repeated until the entire level is mapped, the stations being placed wherever there is a turn sufficient to obscure the light in the portion already surveyed. The other levels are worked out in a similar manner. Shafts, raises, and winzes that connect the different levels should be properly located, for by means of these the position of the workings above or below the levels being surveyed is ascertained. The vertical distance between the levels is obtained by counting the rounds of vertical ladders or by sounding with a tape or cord. It is difficult to represent irregular stopes with precise accuracy, but it is not usually necessary. It is sometimes unnecessary to map all portions of the mine, but the workings in the vicinity of the ore bodies should always be plotted. Even those who have had long

experience under ground cannot hold distances and position in the mind with sufficient accuracy to write a satisfactory description. At critical places greater accuracy may be desired and a tape should be used instead of pacing. When an assistant is not available the geologist should be provided with a few small nails for securing one end of the tape.

In the study of contact-metamorphic deposits it frequently happens that there is a local attraction of the needle due to the presence of magnetic iron. Under such conditions sufficiently accurate work may be done with the plane table and alidade (or with the Gurley compass, used as an alidade) as follows: Set up the plane table at the portal of the adit and orient it by sighting to some known point; then pace the adit as far as possible without losing sight of the plane table, and at this point place a lighted candle; then go back to the table, sight at the candle, and measure off the distance on a suitable scale; stick a needle in the board at this point, which is the location of the candle on the paper; also stick a needle in the board at the initial point, which represents the position of the plane table; on the ground mark the position of the center of the table and remove it to the place where the candle was stationed. Place the edge of the alidade against the two needles and orient the table by revolving the top until the sights are in line with the marker at the initial point. Mark a third station by a candle, then sight to and locate it. In this manner the survey of the level is carried to its completion, the orientation being obtained by backsights to a candle at the station last occupied. If the opening is a shaft instead of an adit, the positions of the shaft timbers may be accurately located and the connecting line used as a base line. If the shaft is far out of plumb and there is only one opening, two weights may be swung in the shaft and a line connecting them used as a base. These methods have an additional advantage for the geologist who is doing surface work with the plane table and pocket alidade and who wishes to make an underground survey of approximate accuracy without a compass or protractor.

The geology is plotted on the level maps just as it would be done on the surface, and the vertical workings are studied as

far as possible. It is convenient to use colored pencils for the different formations. The ore which remains is usually indicated by a red color, filled in solid. Cross lining in the same color is used for ore which has been stoped out. If the value of the ore in different places in the lode is known, this also is noted on the map, with any data concerning the character and position of the minerals which compose the ore. Every fissure, fault, or slickensided surface should be plotted on the level map and the angle and direction of dip should be noted. Conspicuous jointing or bedding planes should also be recorded. As far as possible all the data should be recorded on the map, for this saves time when working on notes and collections. References, either letters or numbers, should be used to give the exact location of observations more fully recorded in the notebook.

The wall rock should be studied carefully and numerous specimens collected. The minerals formed should be noted, for it often happens that the chemical composition of the solutions that deposited the ore, and the physical conditions under which it was deposited, may be ascertained by such study. For the purpose of comparison it is advisable to collect specimens of the fresh country rock some distance away from the lode.

After the level maps are completed, and before the geologist leaves the camp he should draw his cross sections through the mine. These should be selected to show as much as possible of the geologic structure and the relations of the ore bodies to the structure. After this has been done it is a useful practice to summarize briefly the geologic history of the area, with special reference to the deposition of the ore. This should be done before leaving the field, so that the mine may be revisited if necessary. A few hours' work in the evening, when the mind is on the problem and the observations are fresh, may be worth more than a week's work in the office. It is not always possible to form definite conclusions respecting the source of the solutions which deposited the ore, and this is especially true for minor occurrences of ore in a country not extensively developed. Statements of observed facts should be kept free from speculations regarding the genesis of the ore, though the evidence bearing on the latter problem may be summarized in the field with

advantage. Some suggestions are given in connection with the schedule on page 126, which may quicken the observation of the field geologist not familiar with this kind of work.

COLLECTIONS

Purpose. In most cases the geologist has two distinct purposes in the collection of rocks, fossils, and minerals. The first is for making more precise determinations of the character of the materials which the specimens represent than is possible in the field. These determinations may be made by the geologist himself, or the material may be submitted to a specialist for examination. This purpose is wholly served with the completion of the report. The second is to supply material for permanent exhibit in museums or for use in teaching. Both purposes should be kept in mind while the collections are being made.

Numbering and labeling. The specimens of a collection can have no permanent value unless an accurate record of locality and important facts of occurrence is made and connected with the specimens by means of numbers and labels. The expenditure of time and money required to make a collection and instal it in the office is so great that carelessness or lack of system tending to impair the value of the collection cannot be tolerated. Every collector is expected to use some efficient system of labeling.

The specimens of each collection, pertaining to an excursion, a quadrangle, a district, or a given investigation, should be numbered in one consecutive series. It is a good plan to take a letter distinctive of each area and use it as a prefix or suffix to the numbers—for example, D1, 2D, etc. Different members of a party should be assigned different sets of numbers—for example, A might use 1 to 100, B 101 to 200, etc. As specimens and labels may become separated by various accidents, it is essential that the number be placed on the specimen when collected or as soon as possible, and also entered on the map and in notes as elsewhere provided. Small Dennison pasters can be easily carried in an envelope and used when each specimen is taken. If properly put on they seldom crack off. By the use of pen and

indelible ink more permanent figures can be made. Do not disfigure specimens by unnecessarily large pasters or numbers. Neatness goes with proper care.

The label should be a precise statement of locality, collector, date, notebook reference, and perhaps other desirable memoranda. It should be comprehensible to anyone. If symbols and abbreviations are used in field labels, their explanation should be written out when the collection is unpacked at the office. A procedure which saves time in the end is to keep in each notebook a catalogue of specimens so carefully worded as to locality that typewritten labels can be made directly from it.

A locality should not be described on a label by reference to places or features not shown on the topographic map, such as a camp site, or to the point at which some other specimen was collected; the later information is, however, often desirable as an appended explanatory memorandum. Where there is a scarcity of geographic names, it is well to fix the locality on the label by stating with reasonable accuracy the distance and direction from some well-defined point, as measured on the map.

Full details of occurrence cannot be given on a label, but significant data which can be concisely stated should be added when there is room, for example, "From center of dike 15 feet wide," or "Upper contact zone, 3 inches wide, of large sill; see No. — from center."

Collection of rocks. Rock specimens which are to be retained in permanent collections should be reasonably uniform in size and shape. They should approximate 3 by 4 inches in larger dimensions, and be, if possible, less than 1 inch thick. In order that material for extra thin sections or for chemical work may be available for future needs, specimens should not be trimmed too closely. Size and shape are both subordinate to the satisfactory representation of rock characters. The skill necessary to procure well-shaped specimens of massive rock may be acquired in a short time, and should be possessed by every geologist. Collections composed of too large or too small, unsightly, and inconveniently shaped specimens are justified only by unusual field conditions.

Specimens should present fresh, clean fracture faces, as free

as possible from hammer bruises, and care should be taken to avoid staining the specimen through moisture of the hand or in other ways.

Where there are numerous occurrences of a given rock type, the geologist may often wish to collect working specimens to check his field determinations, and these may be of less than the regulation size, but care should be taken that all important rocks are represented by full-sized specimens.

Museum specimens should, so far as practicable, have the size and shape best suited to a representation of the noteworthy features.

Rock chips suitable for thin sections should be inclosed in small envelopes provided for the purpose, and each envelope should be marked with the serial number of the corresponding hand specimen.

Requests for thin sections should be restricted to the actual needs of the work. A small number of carefully chosen chips may be expected to yield more information than several times the number taken at random, with little thought of what they represent.

It is particularly desirable that rocks submitted for quantitative chemical analysis should be represented in the collection by abundant material. Geologists are urged to consider while in the field the possible need for chemical work, in order that the sample submitted for analysis may be truly representative and that there may be on hand several duplicates of such thoroughly investigated rocks.

Where specimens are being collected for complete petrographic study of an area, a large number illustrating all phases of composition and texture will be required. Thus in a transition zone, either of primary origin or marking alteration, it is usually desirable to collect a suite of specimens illustrating the transition. Different numbers should be assigned to different phases. From dikes specimens should be collected from the center, the border, and the contact with inclosing rocks—as many as are necessary to show all phases of texture present. From sills and sheets there should be specimens from the center and both upper and lower portions and from the contact rocks.

In localities which illustrate the gradual transition of one rock into another, series should be collected, showing various stages of the change for chemical and microscopic study.

Each hand specimen should be wrapped separately, either in paper bags or in wrapping or newspaper, so that two or more thicknesses will inclose the specimen on every side. Pebbles, sand, earthy materials, alteration products, etc., should be collected in cloth or paper bags. After a specimen is wrapped it is well to place the number on the package, for convenience when unpacking the collection.

Collection of minerals. The geologist should not neglect opportunities to collect new, rare, or finely developed minerals, even if they have no important bearing on his work. If the collecting involves much time, he should obtain a few representative specimens, making notes of occurrence and locality, which will be useful to the specialist who may wish to obtain further material.

No general rule for the size and shape of mineral specimens can be given. They should represent the best development of the species found, their associations, and the manner of occurrence. Particular care in packing mineral specimens is necessary in order that the time spent in collecting them may not be wasted.

Specimens which illustrate the alteration of any mineral, permitting the study of the process of transformation, are of special interest, particularly if they are pseudomorphs.

Collection of ore specimens. In the examination of a mine or mining district specimens should be collected to represent all the varying phenomena of the ore deposits from the points of view of mineralogical composition, genesis, and structural relations. Collections representing country rocks gathered during the areal survey of a mining district should be made according to the rules already given for rock collections, but the uniformity of size there desired can naturally not be expected to prevail with regard to specimens of ore or minerals.

For a working collection a full suite of specimens of ores, gangues, and wall rocks should be obtained, sufficient to furnish material for a thorough microscopic, chemical, and mineralogical study of the deposits under examination. In these specimens uniformity

of size and shape is not so esential, but they should be large enough to show the phenomena or relations they are designed to illustrate. When intended for complete chemical analysis there should be at least three or four pounds of material. For microscopic examination it is well to break off, in the field, thin chips of appropriate size which will show the phenomena to be studied.

For the museum or reference collection type specimens should be chosen which illustrate as clearly as possible the important and characteristic phenomena of the deposits, such as the original condition of deposition and the results of oxidation or alteration, and of secondary enrichment. In preparing these specimens more care should be taken to approach uniformity in size and shape. A size of 4 by 5 inches with a thickness of not over 2 inches is preferable, but larger specimens may be necessary to illustrate features of mineral association, structure, or relation to wall rock.

For specimens illustrating structure or manner of deposition it is important that it should be possible to orient their original position in the deposits. This may be done by putting a red spot on the upper part of the specimen and an arrow, in indelible ink, on its side to indicate the meridian.

Care should always be taken to avoid bruising or soiling the faces of specimens during the collection. The specimens should be numbered with indelible ink at the time of collection and should be duly described by notes made as soon thereafter as practicable. It is well to assign a letter or letters to a given district and to mark each specimen with that letter and the consecutive number as collected.

Collection of road materials. An important part of the study of road materials is the collection of samples for testing.

The samples should be sufficient in number to represent fairly the road materials of the area surveyed, including deposits having not less than 200,000 cubic yards, and each one should represent the average of the particular deposit sampled. Each sample should weigh not less than 30 pounds. The pieces, in case of rock, should pass through a 3-inch and over a 1½-inch mesh, except one piece about 3 by 4 by 6 inches. They need not be

wrapped separately. If a compression test is desired by the geologist a piece sufficiently large to cut three 2-inch cubes should be included.

Shipment should be made in canvas or burlap bags by freight, and all samples from one locality should be included in a single shipment.

Collection of coal samples. In examining a coal field for the purpose of classifying the public lands or of determining the value of the coal for commercial purposes, it is essential that samples should be procured for chemical analysis. In general, the more important coal beds should receive the most attention, but it is desirable that all coals having a workable thickness should be sampled.

If the geologist is working a field in which there are few or no mines, it will be necessary to procure samples from prospect pits or natural exposures, but care should be taken to avoid sampling weathered coal unless it is impossible to obtain fresh material, and the field is so important and little known that even the poor results to be obtained from weathered coal are essential.

In every field samples should be taken from all the commercial mines, and it is generally desirable to take more than one sample in a mine, especially where there are variations in the coal bed as a whole, in the various benches, or in different beds worked in the same mine. The following rules in sampling mines have been adopted by the U. S. Geological Survey.

(*a*) Never accept weathered coal, but select a fresh face of coal at the point where the sample is to be obtained, and clean it of all powder stains and other impurities.

(*b*) Spread a piece of waterproof cloth upon the floor so as to catch the particles of coal as they are cut and to keep out impurities and excessive moisture where the floor is wet. Such a cloth should be about 1½ by 2 yards in size and spread so as to catch all the material cut down.

(*c*) Cut a channel perpendicularly across the face of the coal bed from roof to floor, with the exceptions noted in paragraph (*d*) and of such a size as to yield at least 5 pounds of coal per foot of thickness of coal bed; that is, 5 pounds for a bed 1 foot thick,

10 pounds for a bed 2 feet thick, 20 pounds for a bed 4 feet thick, etc.

(*d*) Include in the sample all material encountered in the cut, except partings or binders more than three-eighths of an inch in thickness and lenses or concretions of sulphur or other impurities greater than two inches in maximum diameter and one-half inch in thickness. Care should be exercised to keep the groove of uniform size throughout without regard to the material encountered.

(*e*) If the sample is wet take it out of the mine and dry it until all sensible moisture has been driven off.

(*f*) If the coal is not visibly moist, pulverize and quarter it down inside the mine, to avoid changes in moisture, which take place rapidly when fine coal is exposed to different atmospheric conditions. Pulverize the coal until it will pass through a sieve, with one-half inch mesh, and mix it thoroughly so that the larger particles are evenly distributed throughout the mass. After mixing divide the sample into quarters and reject opposite quarters. Repeat the operation of mixing and quartering until a sample of desired size is obtained. When the work has been properly done, a quart sample is sufficient for chemical analysis. Seal the sample in either a glass jar or a screw-top can, with adhesive tape over the joint.

(*g*) The analysis of such a sample will show the grade of coal that may be obtained by careful mining and picking. Generally the sulphur and ash in the commercial output of the mine will exceed the amount shown by the analysis, but the commercial composition can be approximated by multiplying the analytical results by the empirical coefficients 1.06 for sulphur and 1.29 for ash.

(*h*) Accompany each sample by a complete description, stating where and how the sample was obtained and what it represents.

(*i*) In publishing analyses give full descriptions, as noted above, together with the name of the collector, date of collection, name of analyst, and treatment of sample after it was collected.

Stock sampling. As a rule mine sampling will be sufficient to determine the quality of the coal, but in certain cases it may be desirable for the geologist to sample stock piles or even coal

in bins and railroad cars. This is extremely unsatisfactory and no regulations can be given which will insure representative samples. If a stock pile of several hundred tons is to be sampled, the geologist should take at least four large samples averaging not less than 100 pounds each. The sample should be taken from various points on the stock pile, and care should be exercised to include in it the various kinds of coal present—that is, lump, egg, nut, slack, etc. In obtaining these samples it is desirable to turn over as much of the coal as possible, taking an occasional shovelful during the process and being careful to include in the part taken a sufficient number of lumps to get representative coal. Each sample should be pulverized and quartered down according to the rules for mine sampling, and either the resultant samples should be sent to the laboratory separately or the four small samples should be combined, thoroughly mixed, and quartered down. In undertaking to sample coal in railroad cars and bins the geologist will experience considerable difficulty in procuring a representative sample, and no way so far devised has succeeded in accomplishing this purpose. It is possible, however, to procure fair samples of a carload of coal provided they are taken as the car is loaded, the sampler standing in the car and taking a shovelful at stated intervals as the coal is being dumped into the car, being careful to include in each sample all kinds of coal delivered.

Labeling. Sample cans for coal will be furnished on request. These cans will bear serial numbers on the bottoms by which they may be identified. The cans, when issued in connection with land-classification surveys, will be charged against the geologist ordering them, and the chief chemist of the technologic branch will be informed of the numbers issued to each party chief. Blank forms for sending data to the chemical laboratory should be provided and also franked wrappers for inclosing the cans. These blanks will be supplied by the technologic branch. Any can which does not contain an adequate label will be thrown out.

Samples for other than chemical purposes. In addition to collecting samples for chemical analysis, it is desirable to have in the survey for purposes for exhibition and study a large num-

ber of coal samples, especially from the Western field, which contains all kinds of coal from lignite to anthracite. Therefore, wherever practicable samples should be procured for this purpose. Each sample should be of such size as to fill two of the ordinary sampling cans, and no fine coal should be included. The lumps should be carefully selected so as to get representative coal, but at the same time so as not to include any foreign material unless it is so intimately associated with the coal as not to be separable. The cans containing these samples should be sealed and labeled in the same manner as those containing samples for chemical analysis, and they should be sent to the office along with other collections.

Collection of fossils. It frequently happens that the conditions under which geologic work is done render it impossible for the geologist to make full and satisfactory collections of fossils. In such cases, especially when dealing with formations not generally fossiliferous, a record of the localities at which fossils are discovered should be made with sufficient care so that they can be found subsequently without difficulty. The record should contain, in addition to full topographic description and map reference, a statement of the lithologic character of the beds, the character of the fossils—whether vertebrates, invertebrates, or plants—their abundance, their state of preservation, and all conditions affecting their collection.

In collecting fossils there are reasons in addition to those above given for gathering abundant material. For the purpose of determining the exact geologic horizon of a bed it is important to have as many species as possible and to have each species represented by recognizable examples. These two ideas should be in mind when selecting specimens, where transportation facilities are limited, as in reconnaissance work. In more detailed work, even where the formations are well known and their limits recognized, full collections should be made from every fossiliferous horizon of measured sections so far as practicable. The data thus obtained as to the geographic distribution and stratigraphic range of species make future determinations and correlation of horizons increasingly more accurate.

All specimens taken from one bed in one locality, though repre-

senting many species, should be given the same number and label.

As indicated in a previous section, great care should be taken in recording on the map and in the notebook the locality and horizon where fossils are found. As a rule, fossils collected from different beds, even if only a few feet apart, should have distinctive labels, and specimens found on talus slopes or in boulders should be kept separate from those found in place. When collections from distinct horizons are mixed, the fossils themselves will usually indicate that fact; but it will often be necessary to revisit the locality for exact data as to stratigraphy and structure that might have been obtained in the first place if the collections had been more carefully made. Wherever possible, a sketch section should be made in the notebook and the exact horizons at which fossils were collected should be indicated.

Plants. In collecting fossil plants perfect specimens should be sought for; but fragments that illustrate essential or important characters should also be taken—such as the tip of a leaf, a petiole with a part of the leaf attached, a good, perfect base of a leaf, or a well-preserved portion of the margin. By the comparison of a good series of such fragments, if these are all that can be procured, a satisfactory idea of the form, size, and character of the leaf may usually be obtained. In collecting from Mesozoic or Tertiary formations a fragment of bark, a leaf with no part of the margin preserved, or a mass of leaves without form can usually be discarded at once. Occasionally it is of course desirable to take anything in the nature of plant remains, for a few seemingly worthless fragments obtained at a horizon where plants are rarely found may often be of more interest than a full collection from a well-known locality or horizon. In any case it is desirable that the collector spend sufficient time to insure a full or at least a fair representation of the flora at each locality.

In collecting ferns the most valuable specimens are those found in fruit, and nothing, no matter how fragmentary, that shows the slightest tendency to be fruit-bearing should be discarded. As ferns and conifers can usually be determined on smaller fragments than will suffice for dicotyledons, such fragments need not be discarded if no better ones are available. Both these

classes of vegetation are valuable and should be procured whenever possible. Fragmentary impressions of stems and branches, detached leaves of conifers, lignitized wood, etc., are usually of little diagnostic value, and may generally be rejected, except in the case of Paleozoic plants, when great care should be given to the collection of impressions of the outer bark, which is especially essential to the specific determination of such groups as the Lepidodendreæ and Sigillarieæ.

When specimens are accidentally broken all the parts should be saved and kept together if possible. Counterparts or reverse impressions should be carefully preserved and also kept together.

Invertebrates. In collecting invertebrate fossils it should be remembered that the important features for their determination are form, external sculpture, and internal structure. Complete specimens should therefore be obtained if possible, or if the fossils are broken all the pieces should be saved and carefully packed, together with a label indicating that they are parts of one individual.

Imperfect specimens that show internal structure or other important features should be collected even if perfect examples of the same species are obtained. Fossils preserved as internal casts are often more instructive than perfect specimens, but in such cases the adjacent matrix showing the imprint of the exterior should also be carefully collected and kept with with the cast to which it belongs. When fossils are distorted by pressure larger collections are needed to assist in estimating the amount of distortion and thus making the determination more certain.

Vertebrates. In collecting vertebrate fossils it is of the greatest importance to keep the bones of each animal by themselves, separated from all others, and to save all the pieces, however small. Collect carefully all the loose bones and fragments on the surface or covered with earth, before beginning to dig out the skeleton.

Never remove all the rock from the skull, foot, or other delicate specimen. The more valuable the fossil the more rock should be left to protect it.

When an entire foot is found, keep the bones of each toe together and separate from the rest; then the foot can be put

together again with certainty. A complete foot is often more valuable than a skull.

Get all the bones of every good specimen, though it may take much time to dig them out. The absence of a single toe bone may greatly lessen the value of the skeleton.

When a rare bone cannot be got out of the rock entire, it is important to measure its exact length on a piece of thick paper, and pack this, properly marked, with the pieces saved. A drawing of such a bone, however rude, may prove of value.

Small specimens are often more valuable than larger ones, and should be carefully sought for when a good locality is found. Single bones, if one end is perfect, are worth saving. If freshly broken, careful search should be made for all the pieces.

Every fossil or fragment should be wrapped separately in paper, sufficient soft paper being used to prevent all danger of injury by rubbing. Cotton should be used in packing fragile specimens. Each lot that should be kept together, as the fossils from one locality or the parts of an individual, should be put in a sack, or securely wrapped in strong manila paper, with a label inside and a tag or number outside.

Packing. Specimens of all kinds should be packed in small boxes so that they can be handled by one man. Each box should be entirely full, all interstices being filled with soft paper, excelsior, hay, or similar material, but not with sawdust. The top of the box should be plain and the directions marked with paint or ink. Each box should be bound with wire or otherwise strengthened.

CHEMICAL ANALYSES

All requests for chemical analyses should be accompanied by full information as to the locality from which the material comes, the nature of the geologic problem involved, and the bearing of the analysis requested on its solution.

In the case of petrographic specimens, microscopic study of thin sections and a careful comparison of the rock with specimens in the petrographic reference collection already analyzed should precede chemical analysis. A brief statement of the

results of such microscopic study should accompany the request, in order that the chemist may be informed of the presence of unusual constituents or of the abundance of others ordinarily present in small quantity.

When waters are forwarded for analysis the entire material must be collected through filters in clean glass bottles or carboys at one time, so that the entire specimen, measuring not less than two gallons, may be thoroughly uniform, and these vessels must be properly sealed with paraffin. Whenever it is practicable, geologists desiring analyses of water should inform the chief chemist of the general character of the water and receive detailed instructions as to collecting and bottling. Ordinary druggist's filter paper is not suitable for the collection of acid waters.

The nature of the analysis desired should be stated, the elements to be determined being given whenever a partial analysis only is called for. The term "complete analysis" is understood to mean the determination of all the elements which occur commonly in rocks, including titanium, phosphorus, barium, strontium, lithium, etc.

If analyses of this or similar material from the same region have been already printed, the fact should be stated, with references.

The name of the substance to be analyzed should be given, and the locality should be stated on the label accompanying the sample, as well as in the official letter of request.

GEOLOGIC NOMENCLATURE

The advantages of uniformity in the nomenclature of any science are so manifest that they must appeal strongly to every one. The need of agreement in geologic nomenclature is especially urgent by reason of the tendency to excessive multiplication of stratigraphic names with the resulting confusion and burden on the memory. In order to correct this tendency in so far as publications of the U. S. Geological Survey are concerned, a certain procedure has been adopted by the survey in the treatment of matters relating to nomenclature. This procedure is embodied in the following instructions.

"Rules of nomenclature and classification have been adopted for the Geologic Atlas of the United States, and published in the Twenty-fourth Annual Report. Every person doing geologic work in the survey should become thoroughly familiar with these rules. The cartographic unit is the *formation*. Aggregates of formations are designated, in ascending order, *groups*, *series*, and *systems*, and parts of formations are *members*. These terms, when coupled with a geographic name, forming a title, should be used only in the accepted sense, and not loosely or indefinitely.

"The following systems and series are recognized:

System.	Series.
Quaternary	Recent. Pleistocene.
Tertiary	Pliocene. Miocene. Oligocene. Eocene.
Cretaceous.	
Jurassic.	
Triassic.	
Carboniferous	Permian. Pennsylvanian. Mississippian.
Devonian.	
Silurian.	
Ordovician.	
Cambrian	Saratogan. Acadian. Georgian.
Algonkian.	
Archean.	

"Certain rules in regard to the definition and application of geologic formation names, based on principles of priority and established usage, have been adopted by the survey. A committee on geologic names has been appointed to interpret these rules, and geologists and paleontologists must transmit, considerably in advance of the presentation of manuscript, a list of the names they intend to use for all stratigraphic divisions. Moreover, as it is necessary to obtain the committee's approval not only of the new names, but of the particular application of *every* geologic name to be used in the text or on the illustrations, even those to which only a casual reference is made, the manuscript itself must, when completed, be sent to the committee

for examination. This must be done *before* the paper is transmitted for publication, and the author must procure from the committee a letter containing a list of the names used and indicating the action taken thereon, to be transmitted with the manuscript. This regulation applies both to manuscripts for survey publications and to those that are to be published elsewhere, either by other Government Bureaus, by State surveys with which coöperation is being carried on, or in proceedings of societies or scientific journals. In the case of such outside publication, it is especially important that the manuscripts should be referred to the committee, as such manuscripts do not pass through the hands of the survey editor. The committee will give full consideration to the views and wishes of the author, but its approval of all geologic names, both old and new, is essential."

It is generally impossible to decide on the stratigraphic subdivisions or their correlation until the survey of a district is well advanced or is entirely completed, and some office work done. Tentative field names or other designations should therefore be employed and long-distance correlations avoided until the stratigraphic units have been traced to or otherwise identified with formations already defined. Such field names can easily be replaced when final correlations have been made, and no prejudice is incurred in favor of an incorrect correlation.

PERMISSION TO PUBLISH

Control of publication of material obtained at the expense or under the auspices of an official survey should be exercised by the official head of the survey, and publication should be made only with express permission. Formal regulations to this effect are in force in most surveys. The following is the regulation in the U. S. Geological Survey.

"Papers based in whole or in part on material procured or observations made in connection with official survey work may be published elsewhere than in the Survey series only on the written permission of the director. Requests for permission to

publish must be accompanied with the complete manuscripts. The permission will not be granted until the terms proposed to be used have been approved by the committee on geologic names.

"This rule is not intended to hamper in any degree the free expression of scientific opinion or the widest dissemination of conclusions, but it is intended (*a*) to prevent premature publication of results properly belonging in official reports, (*b*) to prevent acrimonious or personal controversy on scientific matters, and (*c*) to prevent inconsistent and conflicting usage in matters of nomenclature and classification."

PART II

INSTRUCTIONS FOR SPECIAL INVESTIGATIONS

PURPOSE OF SCHEDULES

THE following schedules have been prepared with a view to securing system and completeness in making and recording observations. Most of them are not intended to be exhaustive or to cover all possible points on which the specialist will make observations. They are rather for the guidance and help of the specialist when he is working outside his specialty. Thus the glacialist or paleontologist will have occasion at times to make observations on mineral deposits which are being mined or quarried, and the appropriate schedules will indicate to him what points are of most importance and should be most carefully noted. In like manner the economic geologist or petrographer might be at a loss to know what particular features should be observed in a deposit of glacial material. In short, the need for the schedules arises from the extent to which specialization is necessarily carried in geologic work, and they are designed to overcome some of the disadvantages arising from this specialization.

In the field study of economic mineral deposits, the geologist should bear in mind that his results, to have their greatest value, must be based on a thorough knowledge of the geologic relations of the deposits. If he does not obtain this knowledge his work will be a more or less complete failure, no matter how many facts he may ascertain regarding the deposits themselves. If time for the study of a deposit is limited a considerable share should be devoted to the general geology of the district in which it occurs —to its geologic and physiographic history—although these

matters may, to the superficial observer, appear to have little if any bearing on the subject under investigation. The schedules naturally call special attention to facts to be observed regarding deposits of the particular class to which they relate, but it is to be understood that in every case a knowledge of the general geology of the district is to be acquired as a foundation for the special inquiries tabulated in the schedules.

It has seemed desirable to preface the schedules with a somewhat fuller statement of some of the special points to be observed than the tabular form permits. Material assistance has been rendered in the preparation, both of these introductory statements and of the schedules, by Messrs. Whitman Cross, Arthur Keith, G. H. Ashley, W. H. Emmons, A. H. Brooks, P. S. Smith, A. C. Spencer, and W. C. Alden.

DESCRIPTION AND INTERPRETATION OF LAND FORMS

In deciphering the past history of a region the geologist is aided by an understanding of the character and origin of the surface forms. Thus a marine cut bench on a hillside means relative uplift of the land, or a peneplain means a long period of relative stability. The value of this evidence comes from the fact that forms are the result of certain processes acting on certain structures. So, if a particular type of land surface is observed the geologist may deduce the processes that have been effective, or the history or genesis of the area. As such deductions constitute the main use of this kind of evidence from the standpoint of the geologist, those points which serve this end should be particularly sought.

The description and interpretation of land forms can no more be treated adequately by long-range views alone than can stratigraphy. It is desirable to gain first a broad view of the region, then to study the features in detail, and then to assemble the facts collected by these two methods of observation. Such study should consist of both office and field work, neither alone giving the best results, although the latter is far more important than the former.

Office study should precede and also follow the field work, but as the compilation of the results differs but slightly from the method pursued in other sciences, it need not be discussed in detail here. The aim of modern science is to make use of time most effectively. Therefore, when any work may be done equally well by two methods, the shorter one is to be chosen. Much time may be saved by a study of maps and the literature before visiting a region. In this study the relation of the particular area to the larger land forms outside of it should be noted, as well as the main features within its limits. In this preliminary study any peculiar features which will require particular attention in the field, such as abrupt termination of ridges or sudden changes in the direction of the streams, should be noticed. The general arrangement of the various topographic units should be grasped, and so far as possible, a plan of campaign laid out. As much information concerning the geologic structure, climate, etc., as is possible should be gained, but the attempt should not be made to do those things which can be better done by observation in the field.

Subdivision of land forms may be carried to any degree of refinement desired. In the accompanying schedule (No. 1) three types—plains, plateaus, and mountains—are adopted, and it is believed that all areas which are encountered by the field geologist will belong to one or more of these types. Each of these divisions may be treated as consisting of three parts: the upland, the valleys, and the intervalley areas, or spurs. Each of these details should be considered, first separately, and then in its relation to the others. When this has been done, the observer will be in a position to undertake the statement of the origin of the present form. The character of the previous form, of which the present form is a derivative, next requires attention. It may be best deciphered by one alert to the forms characteristic of each agent of land sculpture. Thus, if a peneplain is suggested, evidence of old age should be sought in the character of the drainage, deep rock weathering, absence of ledges, absence of undrained areas, monadnocks, lack of interruption of peneplain surface on rocks of very different resistance, etc. If these conditions are not fulfilled, their absence must be explained, or

the interpretation is erroneous. After a hypothesis is formulated, it should be tested by some new line of study, for every hypothesis must at least fit the known facts, but its probability is increased in proportion as it explains some previously unexpected facts. For instance, the theory of continental glaciation was first advanced to account for scattered boulders of foreign material which showed scratched surfaces. When this theory was tested by inquiring the effect of such a hypothetical ice sheet on the drainage, and was found to explain perfectly such conditions as those in the region around the Great Lakes, it commanded greater credence.

While much of the theoretical consideration of the data required can be profitably worked out after returning to the office, it is of prime importance that the greater part should be done in the field with the forms before the observer, for in that way suggestions may be tested and critical localities visited. If, however, the time for field work is limited, enough information for a general description may often be afforded by photographs. In taking pictures it is important to note the compass direction in which the camera is pointed. Furthermore, if possible, at least two views, at right angles to each other, of all important features should be obtained. Notebook sketches are of great value, especially in supplementing photographs, but the personal interpretation should not obscure the facts, for it may be necessary to modify early opinions in the light of further knowledge.

In the use of the accompanying schedule, which is primarily intended for field observation, it should be remembered that often only a few of the points necessary for a complete description may be found in a single view, and therefore answers to every one of the headings indicated on the schedule are not expected. The object of the study should be kept firmly in mind and emphasis placed on those portions which further the main object of the party. The observer should be alert for corroborative evidence that can be obtained from all the branches of geology, as, for instance, stratigraphy, petrology, etc.

PETROLOGIC OBSERVATIONS

Rocks are the documents that contain a large part of the geologic record. To read that record is the geologist's duty, and it will not do to jump at the sense by catching a word here and there.

Rock masses represent primarily the result of certain processes, acting on certain materials, under certain conditions. Petrology is the broad science of rocks, dealing with the product and from a study of its characters and relations reaching conclusions as to these processes, materials, and conditions. These processes include metamorphism and decay of rocks, the latter being but an initial process in the forming of still other rocks.

For the geologic interpretation of rocks the primary requisite is a knowledge of the rock itself. In proportion as its characters and relations are known its significance as a geologic mass is understood. It is, then, manifestly a primary duty of the field geologist to study carefully in the field the rocks which come under his observation and to provide adequate material for refined examination in the office or laboratory. It is important for him to realize that the more fully the character of a rock is appreciated in the field the more helpful are its hints in directing the course of investigation.

Some of the important things to observe in connection with different classes of rocks will be briefly mentioned here.

IGNEOUS ROCKS

Rocks representing fused material from unknown sources in the earth's interior are seemingly primary. If derived from older rocks only the general chemical nature of these original rocks can be inferred. The igneous rocks are of great importance as telling almost all that we know of the earth's

interior and illustrating many principles of chemistry and physics.

Character of the rock. Observe mineral composition and texture carefully; the proper classification, description, and naming of a rock depend on these factors. Note variation of either composition or texture in a given mass; both require explanation. Heterogeneity in composition is often difficult to explain. Is it related to form of mass or to contact zones, or is it irregular in distribution? Is the transition from one phase to another sudden or gradual?

Changes in texture indicate conditions of consolidation. Dense or glassy contact zones with coarser interior show the chilling effect of cold wall rock, water, or the atmosphere. An even, granular texture in contact zones speaks for highly heated country rock, produced perhaps by the passage of much magma through a conduit, or a great depth of the mass at the time of consolidation. Fluidal textures in contact zones imply movement just before consolidation.

Mode of occurrence. Observe form, size, and position of intrusive masses with relation to character of the rocks, with reference to the history of the region, and for data bearing on the question of the mechanics of igneous intrusion. Do the contact zones of intrusive masses, either with wall rock or included fragments, show evidence of fusion of wall rock or inclusion and assimilation of melted material, or is the contact sharply mechanical? If large fragments are included in an intrusive rock see if their source can be determined. Specimens illustrating these relations are necessary.

Relations of rocks. Where several igneous rocks occur in association, observe relations of occurrence and evidences of relative age of different kinds. If one cuts another ascertain which is the older. Contact modifications in the younger rock are common. The sequence of eruptions is often interesting as bearing on magmatic differentiation and the succession of events at a volcanic center.

In many places small masses or dikes are characteristically associated with certain large bodies. Note such restrictions of

occurrence and represent different dikes liberally by specimens.

Effusive rocks. The petrographic character, features of association, and succession are matters of prime interest in connection with effusive as well as with intrusive rocks. It is important to determine the location of the vent from which a lava has issued and its connection with or seeming independence of a center of typical volcanic action. If a volcano is indicated problems arise as to the nature of the eruptions, whether effusions of lava or explosive outbursts, the period of activity, and the extent and state of preservation. In the case of ancient volcanoes which have been greatly eroded the phenomena may become largely those of intrusive rocks.

Observe carefully the extent and thickness of lava flows and the features of their upper and lower zones and of the surface. These points bear on the liquidity or viscosity of the magma as it issues from the vent. The more liquid lavas flow readily and cover a larger space than those that are viscous, some of which build up domelike hills above their vents.

Metamorphism. Always study with care the change produced in a country rock or an included fragment by an igneous magma or associated solutions. Ascertain the original character of the wall rock and the extent of its metamorphism, as shown by gradation from maximum to minimum effect, the latter being commonly related to distance from the intrusive body. Note the character of the secondary minerals when possible and illustrate by specimens.

Decomposition. The destruction of an igneous rock is usually accomplished by deep-seated chemical action or by the dominantly mechanical processes of weathering near or at the surface. In the former case the special characters of a given rock may be changed by the work of circulating waters. Certain components may be removed and others brought in. Thus rocks of different primary character may be brought to resemble each other and even the distinctive properties of an igneous mass may disappear, as in extreme silicification or kaolinization. Such alteration is usually so localized that the geologist may

observe various stages, even perhaps to the fresh rock, and by obtaining suitable specimens afford means for an interesting study. Consider especially the relation of such decomposition to ore deposition.

Study the surface decay of rocks with relation to the process of weathering, the formation of soil, the mechanical destruction of the exposed mass, and the deposition of detritus.

Pyroclastic rocks. Intermediate between massive igneous and sedimentary rocks in some respects are the pyroclastic rocks. They may represent débris from volcanic explosions which has fallen on the slopes of the volcano or at no great distance and has suffered no transportation. Contemporaneous, and perhaps intermingled with such deposits, may be others that have been washed, by heavy rains attendant on eruption, to varying distances down the slopes or into bodies of water. After eruption ceases volcanic débris is naturally transported and deposited at more or less remote points in normal sediments.

Make observations to determine the relations of pyroclastic deposits to their source both in space and time. Sediments composed of volcanic material transported, sorted, and deposited under usual conditions exhibit the characteristics of clastic rocks referred to below. As a rule those which belong essentially to the volcano exhibit structural relations to the volcanic center, association with lava streams, irregular mingling of coarse and fine particles, crude bedding, and petrographic uniformity as to constituents. The finer particles are sharply angular, many of the larger ones are somewhat rounded, and bombs are of common occurrence.

Collect specimens wherever desirable, following the instructions in this handbook in regard to form, number, label, and record.

Summary. The following statement summarizes the observations to be made on igneous rocks:

Observations.	Significance.
1. Megascopic character of rock as to (*a*) composition, (*b*) texture, (*c*) uniformity or variability in mass, (*d*) relations of all characters to features of occurrence, (*e*) specimens.	1. The excellence of petrographic classification, description, and nomenclature depend on the thoroughness of these field observations, which may also bear on the causes of textural or mineral differences of rocks and many other problems.
2. Mode of occurrence—batholith, stock, dike, sill, laccolith, flow, tuff, breccia, or agglomerate.	2. Physical features of origin, historical connections, and meaning of many characters of rocks.
3. As to method of intrusion: (*a*) Are contacts sharply defined? (*b*) examine wall rock or inclusion for evidence of fusion and assimilation; (*c*) search for source of large inclusions.	3. Contribute to determination of the methods by which batholiths, stocks, etc., come to place Opinions differ.
4. Relations of rocks of a series as to occurrence, age, and mass.	4. Bear on history of eruptions and magmatic differentiation.
5. Character and extent of contact metamorphism, associated ore deposits, and attendant alteration of country rock.	5. Character of magma as to its associated gases and solutions.
6. Seek source of a lava flow and its association with other flows or with pyroclastic material. In case of a series study sequence and structural relations.	6. Associated lavas indicate a volcanic center whose history should be deciphered if possible; the extent, nature of eruptions, and degree of dissection.
7. Pyroclastics:	
(*a*) Chaotic arrangement, or rude bedding, angular form of smaller particles, association with lavas, dip from a center.	7. (*a*) Characters indicate that beds are directly of volcanic origin, have suffered little transportation, and may represent part of old volcano.
(*b*) Rounded particles, distinct bedding, admixture of nonvolcanic matter, fossils.	(*b*) Transportation and deposition under conditions common to ordinary clastics.
(*c*) Bombs or glassy droplike particles in deposit.	(*c*) Derived from explosion of liquid lava.

SEDIMENTARY ROCKS

Much of the history of the earth's surface in past ages is recorded in the sedimentary rocks. The geologist's interest in them is many-sided. Beyond and above the purely petrographic interest lies the consideration of the sediments as geologic units to be interpreted in their bearing on earth history. Primarily this is a question of the rocks as deposits.

The clastic sediments tell of older rocks destroyed, of detritus transported by various agencies, and of deposition under many differing conditions. Such deposits must, then, be studied for the light they throw on the conditions and events of the epoch they represent.

The sedimentary rocks other than clastics are chiefly precipitates from solution and their most evident importance is in connection with the place and conditions of deposition. Most of these rocks owe their origin to the action of organisms, directly or indirectly, or to the desiccation of isolated bodies of water.

It is manifestly impossible to give here more than a suggestive outline of necessary observations concerning features of sedimentary rocks, with hints as to their significance.

CLASTIC ROCKS

Petrographic character. Comparatively little attention has been paid by petrographers to the inherent properties of clastic rocks. The meager terminology is evidence of this neglect. The difficulty of interpreting the conditions under which sediments were deposited is no doubt due in part to imperfect knowledge of the character of the sediments themselves; hence closer study of the rocks is highly desirable for the advancement of both petrography and stratigraphic geology. The nature of the rock particles in a sediment should be determined sufficiently to permit the use of appropriate names and descriptive terms and to lead to the recognition of peculiar or characteristic features of formations under investigation. "Sandstone" is too often

used as a sufficiently exact lithologic term. It is important to know whether the sand grains are quartz, feldspar, calcite, volcanic ash, or other materials of peculiar character. "Conglomerates" are often described with no mention of the character of pebbles or of the usual sandy matrix. Such deficient description is usually due to deficient observation.

Source of materials. The mineral and rock particles of sediments should be examined with care for their evidence as to the character of existing land masses of a given epoch. By this evidence an important stratigraphic break may be detected in an apparently conformable series of beds—a break corresponding to overlap in some districts. The pebbles of conglomerates and the particles of the coarser grits and sandstones will often yield this information on megascopic study, but specimens for office examination should be taken. The microscope may show that a certain sandstone is derived largely from quartzite and not from granite or other igneous or metamorphic rocks.

The site of land areas furnishing débris is in some places indicated by increasing coarseness of conglomerates in the direction of their source or by restricted distribution of certain components.

Transportation and deposition. Rock detritus may now be seen in all stages of transportation from sources far inland to the sea, and much is known of submarine deposits. Wind, ice, and water are visible agents of transportation. Presumably some ancient clastic deposits represent nearly every stage of each process of transportation. The recognition of the stage or process must be the ultimate aim of the geologist.

Most wind-blown material is in the end transported and deposited by water, but glacial débris representing till or moraine may be preserved as such, with slight modification. Recent studies of certain ancient conglomerates have led to the belief that they represent till. The subangular form and striated faces of pebbles and the irregular texture of the matrix, showing no evidence of sorting by water, constitute the decisive criteria in this case.

Sediments formed above sea level are grouped as *continental.* They clearly include lacustrine, river, and land deposits and the question of their importance relative to marine beds among the ancient formations is one of the chief problems of modern

stratigraphy—a problem which the geologist should have constantly in mind. Studies of nonfossiliferous marine and continental clastic rocks of similar textures, tending to determine critical differences between them, are much needed. The various phenomena of nearly all kinds of sediments must be studied together and finally interpreted in the light supplied by the association of characters.

Attention has been particularly called to certain features of clastic sediments in illustration of the preceding remarks, but it must be realized that characters not here referred to may be of great importance in special cases.

Fossils. Fossils should be sought with great care in all deposits, not only for their chronologic significance but also for the evidence they furnish as to conditions of sedimentation. Many marine and fresh-water beds are distinguishable only in this way. Remains of land animals, especially of dismembered vertebrates, may exhibit marks of abrasion, suggesting the fluviatile character of the sediments containing them. It may be that fragments of fossil wood or bone have been derived from older strata—a possibility to be kept in mind.

Character of particles. The size and form of the particles in a sediment are often highly significant. Large size and angular form indicate that fragments have not suffered transportation to a great distance from their source. Small and rounded sand grains have presumably traveled far or suffered attrition by wave or wind action. Fine mud is not necessarily the product of extreme transportation. It may result from erosion of fine-grained deposits near at hand or from wind erosion in an arid region.

Homogeneity of deposits is a factor of various aspects. It may indicate a near-by source of material—a land mass mainly of limestone or quartzite or some other prevalent rock—or it may tell of volcanic outburst, as in the case of a tuff. On the other hand, there is a textural homogeneity produced by long-continued sorting by water, in which size, specific gravity, or hardness of minerals sorted is usually the controlling factor. This is illustrated by a quartzose sandstone.

Heterogeneity in character of clastic components may testify to the destruction of a complex land mass; or, if the rock is

a mixture of certain minerals in notably uniform proportion, as in some arkose grits, a granitic or gneissic source may be inferred.

Texture. The uniformity or variability in texture of sediments should be carefully noted. A stratum possessing uniformity over a great area implies uniform conditions in that area; the vertical extent of such strata tells of continuance of conditions in time. Such uniformity is most common in subaqueous sediments but is also shown by some fluviatile and basin deposits.

Variability in texture is indicative of restricted or rapidly changing conditions, such as those of most continental and some offshore marine deposits.

Bedding. The bedding of sediments is of much significance. Where bedding planes are closely spaced, notably even, and laterally persistent, they tell of quiet waters and slow accumulation of material; where they are far apart they show rapid accumulation, commonly in turbulent waters. Cross-bedding is indicative of wave action or great river currents and must be studied in the light of other characters of the strata.

Color. The color of strata is of extremely variable importance. Observation should determine whether a given color is characteristic of a formation, is restricted locally within it, or transgresses formation limits. The cause of its color and whether this is of primary or secondary origin must be determined, and these problems usually require office study. The color may pertain to the clastic particles, to the cementing substance, or to a pigment of later origin than the deposit.

The red color common to many formations is of particular interest. It is often considered diagnostic of the basin deposits of arid regions or of material derived from such areas. The usual absence of fossils in red beds and the ferruginous nature of the pigment are points in favor of a climatic significance for red strata. But certain red deposits are plainly derived from older red rocks and hence generalizations must be based on close observation.

Markings. Various markings made on the surfaces of mud deposits before they were covered and preserved by succeeding layers are of notable value in showing certain conditions of deposition. Mud cracks, raindrop pits, organic trail marks, footprints, etc., testify to exposed mud flats. These need not be of tidal

origin, as is sometimes assumed, but characterize as well the flood plains of rivers, marginal plains about lakes, and the interior basin deposits of temporary lakes, especially in desert regions. Ripple marks and allied forms belong chiefly to the littoral zone of lacustral or marine beds, or to fluviatile deposits.

Cement. The cementing material of many clastic rocks is a strikingly characteristic feature. It may have been formed at the time of deposition, as in calcareous sandstones and marls laid down in sea water rich in lime. It may have been gradually deposited from waters circulating through the porous rock long after its formation, and although such cementation is a change in the character of the sediment it is not commonly included under metamorphism. The induration of a clastic rock may, however, date from some period of intense chemical activity, and thus be classed as metamorphic change.

It is evidently desirable to investigate the induration of sedimentary rocks and determine the nature of the cement and, if possible, the time of its deposition. Lack of cement may signify that the sediment has never been saturated by waters capable of depositing a binding substance or that solvent waters have abstracted the former cement.

CHEMICAL AND ORGANIC SEDIMENTS

Chemical precipitates and rocks consisting of organic remains are simple of interpretation as compared with clastic rocks, but tell little beyond the conditions of their deposition.

Limestone is the most important sediment of chemical origin. As it is in many cases produced by the aid, directly or indirectly, of organisms, fossils are apt to be present and should be diligently sought. Marine and fresh-water limestones are thus to be distinguished. The name limestone is often indiscriminately applied to carbonate rocks regardless of the amount of magnesium and iron carbonate that may be present. Material for investigation of composition should be collected, and it may be desirable to carry a small bottle of hydrochloric acid to discriminate magnesian limestone. It is important to note the character of impurities in limestones—their texture, fracture, bedding, and color. The cause of characteristic colors should be determined.

Gypsum and salt deposits, even if not of industrial importance, are significant of lagoons or of isolated seas, and usually testify to arid climatic conditions, which may also often be inferred for associated clastic sediments.

The now recognized continental character of carbonaceous deposits derived from land plants sheds also much light on the nature of associated rocks.

Summary. A summarized statement of the observations to be made on sedimentary rocks is subjoined.

Observation.	Significance.
1. Accurate determination of character of constituent particles, character of cement, and texture.	1. Basis for petrographic treatment and deductions as to history of rock.
2. Search for particles derived from older rocks of recognizable character, particularly pebbles and larger particles.	2. Show character of land masses exposed. May demonstrate stratigraphic break.
3. Study general character, extent, and associations of rocks as forming geologic units.	3. Bear on methods of transportation and conditions of deposition.
4. Search for and collect fossils.	4. Age and condition of deposition.
5. Special characters:	5.
(*a*) Large and angular fragments.	(*a*) Proximity to source; probable continental deposit.
(*b*) Small, rounded grains.	(*b*) Transportation and sorting.
(*c*) Homogeneity of stratum.	(*c*) Character of source or degree of sorting.
(*d*) Heterogeneity of stratum.	(*d*) Complex source or possibly fluviatile deposit.
(*e*) Great variability of characters.	(*e*) Common in fluviatile and offshore deposits.
(*f*) Bedding; spacing of distinct planes, extent (lateral or vertical) of uniform character.	(*f*) Continuity of conditions areally or in time.
(*g*) Cross-bedding.	(*g*) Wave action (subaqueous) or current (fluviatile).
(*h*) Color; does it belong to fragments, cement, or secondary pigment.	(*h*) May indicate source of débris, or constitute a diagnostic feature as to conditions of time of deposition.
(*i*) Mud cracks, raindrop pits, organic trail markings, footprints.	(*i*) Indicate exposed mud flats, tidal, flood plain, or lake margin, or interior basin.
(*j*) Cement material; its character and amount; is it primary or secondary?	(*j*) May have diagnostic value in recognition of bed, or denote change long after deposition.

METAMORPHIC ROCKS

General observations. Igneous and sedimentary rocks alike are subject to change by many different angencies operating under various conditions and subject to recurrence at distinct periods. The changes vary in degree, ranging from a barely perceptible alteration to the total obliteration of the primary characters. In the introductory text of the geologic folios metamorphic rocks are defined to include those in which "the newly acquired characteristics are more pronounced than the old ones." It goes without saying, however, that all degree of metamorphism should be studied with care. Important studies both of weathering and of deep-seated metamorphism require an appreciation of the problems while in the field and an intelligent selection of material for detailed examination in the office.

The observer must remember that metamorphic rocks have a threefold interest. First, the rocks themselves are notable because many of their acquired characters, both of mineral composition and texture, are peculiar to them. Second, they represent igneous or sedimentary masses, and recognition of their original nature leads to information concerning epochs preceding the metamorphism. Third, the processes by which the metamorphism has been accomplished are important from the physical and chemical as well as from the historical standpoint.

Painstaking observation of megascopic characters is, if anything, more necessary than in unaltered rocks. Compared with igneous rocks the crystalline schists exhibit marked variations in composition and texture within a given geologic mass, and study of these features may furnish important lines of evidence. By discriminating phases of rocks varying degrees of metamorphism may often be recognized, and where several stages are known both the nature of the original materials and the processes of alteration may be worked out. All stages must be represented by specimens for detailed study.

Different rocks acted on by the same agents differ greatly in their susceptibility to change. Thus shales become slates, giving

evidence mainly of mechanical changes and often but slightly of chemical changes, whereas feldspathic sandstones and impure limestones are readily altered to highly crystalline schists. Conglomerates or porphyritic igneous rocks often form the basis for layered schists, and some fissile hornblende schists are traceable into diabase or diorite.

In areas that have suffered regional metamorphism it sometimes happens that no trace of primary minerals or textures can be recognized and even larger structural features are greatly obscured. In such areas rocks rich in quartz or in calcite may furnish clues to the determination of the original sediments. Layering in schists and gneisses may or may not represent stratification.

In areas of contact metamorphism it is usually possible to determine the course of alteration by studying the progressive change in passing away from the intrusive mass.

In studying all phases of metamorphism it is of the greatest importance to determine if materials have been added or subtracted, one or both, or if only the substances of the original rock appear in the metamorphic product.

Metamorphism of all sorts may be attended by the segregation of metallic minerals and the formation of workable ores.

Summary. The following points, therefore, are of prime importance in the study of metamorphic rocks:

(*a*) Determine the large features and structural relations of the original rocks considered as formations.

(*b*) In all classes of metamorphic rocks seek the most and least altered phases; estimate the nature of change from one to the other.

(*c*) Study all phases of alteration in order to establish a progressive series. Even if incomplete such a series may indicate the processes of alteration.

(*d*) Distinguish mere mechanical metamorphism from molecular and chemical change.

OBSERVATIONS IN STRUCTURAL GEOLOGY

The facts of geologic structure should be gathered for three purposes:

(*a*) For use in determining the thickness and sequence of formations and in directing observations in the field.

(*b*) For controlling the drafting of maps and sections.

(*c*) For deciphering the history of the earth.

For immediate field purposes. It is obvious that dip and strike should be observed in order to calculate the thickness and sequence of the rocks. Once those factors are determined they can be used to detect other structures, like faults and duplications that may be locally obscured.

Metamorphic products also must be observed in order to trace and correlate formations which were originally the same but now are locally changed.

An early understanding of the faults and folds of a region is essential to mapping and guides the geologist to critical localities. So, too, it is of the utmost importance in the study of economic deposits, some of which, like coal, oil, and gas, are more or less available according to their position in the folded and faulted strata. Metalliferous deposits may follow the contact of two formations, lie in certain fissures, follow fault planes, or fill the lower part of the synclines, and to mine them best an intimate knowledge of the structure is needed. A knowledge of the relation between deposits and structure will lead to the discovery of new and unsuspected deposits.

For drafting purposes. In the drafting of maps a knowledge of the dip of strata along the formation boundaries is essential in order to show properly the curving boundary lines produced by various topographic forms. These variations are of small consequence where the dips are over 60°, but are of radical importance if the dips are 20° or less.

In drafting structure sections a knowledge of the dips of the strata will frequently determine the presence of a fault, where in the body of a formation there are no visible offsets or dislocations. It seems hardly necessary to state that the dips should

be recorded in the field as well as seen, but there is a common tendency to omit them from the record. A proper procedure is to put into the notes the dip and strike of every rock about which any comment is made. This suggestion applies to dips of cleaveage and schistosity as well as to those of stratification.

For historical purposes. Most of the facts that are noted in regard to rocks record their environment—the conditions which led up to their production. Still other events, those that followed the formation of the rocks, can be deciphered from their structure. In the sedimentary and igneous records there are many gaps. These are bridged, in part, by the facts of structure.

One series of rocks may rest across the beveled edges of an older series, thus showing that the earlier rocks were uplifted, worn away, and depressed again by further movement before the later rocks were deposited. The pressures may have been great enough to fold or break the older rocks, or even to alter their minerals, while similar facts may not be shown in the second series. These are signs of the greater earth events and from them the geologist infers that the time between the series was of great duration.

Some large areas are characterized by faults of normal type. It may be concluded from this fact that the thin layer now visible has been deformed without horizontal compression and has merely accommodated itself to the disturbed underbody of the earth.

Other great districts exhibit rocks folded in troughs and arches, or piled over each other on faults. Such facts clearly indicate that the visible part of the earth's crust has been enormously compressed and shortened horizontally.

Still another region may contain rocks whose textures and minerals are more or less altered from their original condition. These phenomena show clearly that either the pressures producing them or the load of overlying rocks were at their maximum and entirely overcame the strength of the metamorphosed beds.

Thus, in one part of the country or another, rocks are now exposed at the surface which slowly came up to it from greater or less depths. They contain records—fragmentary, it is true—of the conditions through which they passed at different levels.

A gabbro, for instance, may have been intruded into other rocks at a very great depth. Dynamic movements at some later time combined with the weight of overlying rocks to transform this rock into a hornblende schist or gneiss. In different parts of its mass both altered and unaltered phases may still be found. By erosion the mass approaches the surface and lies in succession in the zones of flowage, of fracture, and of weathering. Evidences of processes in all these zones may be found in the rock—close-knit crystalline minerals for the first; joints and dislocations more or less filled by later minerals for the second; and gradual expansion, disintegration, and hydration for the third. During this rise to the surface the rock may have been affected by a second compression, and the structures produced by this process will be seen modifying those of the first.

In brief, it can be seen that the record of structural geology begins where that of sedimentation or intrusion ends, and that each is a necessary complement to the other. Concurrent with and modifying each were the processes of erosion. These furnish a record of still broader and simpler dynamic movements —those of uplift, depression, and warping. Some large districts are marked by an almost entire absence of geologic structures. In them the geologist's insight into the past is sadly limited.

GLACIERS AND GLACIAL DEPOSITS

Existing mountain glaciers. It is of importance to note the phenomena of existing glaciers, both because of their own interest and because of their value as indicating general atmospheric and climatic conditions and also as affording a means of interpreting the mode of action of ancient mountain and continental glaciers and the part played by them in the history of the earth.

Observations should be made wherever possible on methods of erosion, derivation of the drift, transportation, and deposition.

Note should be made of indications as to whether the ice is stationary; advancing and crowding on moraines and bordering

terraces; encroaching on lakes, marshes, or forests; discharging icebergs to the sea; or retreating from its moraines.

Earlier mountain glaciation. It is of importance to ascertain the conditions prevailing in mountain districts during Pleistocene time and to develope means of correlating glacial phenomena of the mountains and of the plains with non-glacial phenomena, such as those due to lacustrine, fluvial, and marine agencies of the same time.

In some places earlier prevalent conditions were so different from those of the present that glaciers occupied valleys and slopes which are not now glaciated, and many of these earlier glaciers extended to lower altitudes, some of them reaching the seacoast or lacustrine basins in such a manner as to afford means of determining the time relations of the glaciation and the submergence.

Wherever possible observations should be made on the deposits of earlier and more extensive glaciers, and these should be discriminated carefully from non-glacial deposits. For example, in examining the high-level gravels of the mountain districts and similar deposits look for faceted and striated pebbles and boulders, lack of assortment, and stratification by water, and the presence of erratics too large for water transportation; note the maximum size of stones and their topographic situation; look for glaciated rock surfaces near or beneath the deposits.

Pleistocene continental glaciation. In the study of Pleistocene glacial phenomena it has been determined that the epoch did not consist simply of the development, extension, and melting of a single continental ice sheet, but that, on the contrary, there were successive stages of glaciation, each marked by the development, extension, and final melting of an ice sheet; that these glaciers deployed from more than one center and differed considerably in extent and in the directions of their movement; that the stages of glaciation alternated with stages of deglaciation, when such climatic changes occurred as resulted in the melting of the ice sheets, the development of new soils, and the introduction of new faunas and floras. During these stages of glaciation and deglaciation a great variety of phenomena were developed as a consequence of variations in the extent of the

different advances and retreats of the ice fronts and in the methods and amounts of erosion, transportation, and deposition. The character of a large part of the northern half of North America, and its adaptability to human habitation or at least to the carrying on of particular pursuits, are in large measure a consequence of these geologic processes.

Much of the science of glaciology is still in a formative stage; for instance, the number of the glacial and interglacial stages, their relative length, the character of the attendant climatic changes, the attitude and altitude of the different parts of the continent, the relation of glacial phenomena to non-glacial phenomena south of the drift limit, and many minor phenomena are not yet satisfactorily demonstrated, nor are the causes of Pleistocene glaciation yet so well understood as not to need the development of new hypotheses. It is therefore of importance that a large amount of detailed data based on careful observation be accumulated, not only as the means of interpreting the geology of particular areas but for the development of the science itself. From the nature of the case, dependent as continental glaciation was on the climate and geography over wide areas, it is necessary that the study of the phenomena be carried on throughout areas of great extent and under widely varying conditions, and observations should be made wherever possible. For instance, in determining the age of a particular glacial deposit it is impossible, merely by collecting and identifying fossils to refer the deposit to its proper horizon. If the stratigraphic relation cannot be traced directly, the geologist is dependent on the observation and correlation of a large mass of data concerning the composition of the deposit, derivation of material, direction of ice movement, degree of decomposition by weathering, maturity of development of the drainage systems thereon, and other phenomena in order to form a reliable opinion concerning its age.

As a basis for the glacial study it is essential to have some knowledge of the general geology, the constitution and attitude of the different rock formations, and their relation to the topography of the bed-rock surface, both in the area to be studied and in the region traversed by the ice in reaching this area. The

action of the ice in deploying, in eroding, and in forming the several classes of its deposits depended largely on the configuration of the bed-rock surface overridden by it. For a knowledge of the character of this surface beneath the drift a study should be made of the streams with reference to their continued occupancy of, or diversion from, their preglacial courses. For this purpose the character, locations, and dimensions of rock gorges, falls, and rapids should be examined with reference to the broader parts of the valleys that are now wholly or in part filled with drift. Records of wells and other drillings afford the means of tracing these buried watercourses. The study of the relations and dimensions of the earlier and later watercourses and the presence of glacial drift, loess, and lacustrine or other deposits in them may afford measures of the time elapsing before, between, or since two or more successive ice invasions.

The composition of the drift in various parts of an area depends on the character of the rock formations overridden, so that the two should be studied together. The presence, as constituents of the drift, of rocks not otherwise known to occur in the region (such as the occurrence of diamonds in the drift of the Mississippi Valley) may also give clues as to their character and locations. Rough analyses of the lithologic composition of the drift may readily be made by taking indiscriminately from a section of drift one to several hundred pebbles and sorting according to their character. In doing this, however, note should be taken as to the contribution of friable sandstones, soft shales, etc., which are easily comminuted but do not persist as pebbles or boulders.

Study of the distribution, structure, composition, and mode of origin of the several forms of deposits made by glaciers and their attendant waters, besides its general application, affords the means of working out the details of local geologic history and of explaining many features of the topography which are of great interest, especially in educational work.

Exposures of interglacial soils and vegetal deposits are rarely seen, and where found should be carefully studied, as the included organic remains may afford important evidence as to the climate and consequent probable extent of deglaciation of the region. The location of such a deposit relative to its distance from the

margin of the overlying drift may have like import, even if the deposit is not exposed but only known to have been penetrated in drillings. Where no organic remains occur the degree of weathering and of leaching of calcareous drift in connection with a buried soil may afford data as to the interval elapsing between the melting of the earlier sheet and the burial of the drift by subsequent deposition.

Schedule 4 (p. 126) indicates phenomena on which observations should be made where there is opportunity.

INVESTIGATION OF PRECIOUS AND SEMIPRECIOUS METALLIFEROUS DEPOSITS

After as thorough a study of the general geology of the district as possible has been made, the following points in connection with the ore deposits should receive special attention:

Openings in rocks. Since most ore bodies are deposited by aqueous solutions, the channels through which such solutions circulate are of great importance. An opening of any kind may serve as the seat of ore deposition. A cave in limestone, a permeable bed, such as a sandstone, a conglomerate, or an amygdaloid, may furnish the open spaces necessary, but most of the metalliferous ore deposits are related to openings which have resulted from movement. It is desirable to study the character of the openings and their relations to each other, to jointing, and, if they are in sedimentary rocks, to bedding. It is not always possible to obtain data regarding the fissure itself, for processes which attend deposition frequently obscure the evidence of fissuring and the ore body may be the only evidence of the opening which remains. This is especially true of replacement veins in limestone.

In some places certain rocks have been formed more recently than the ores, and where this is so it is desirable to establish the fact as definitely as possible, for it is obviously of great economic importance. Again, some rocks because of their greater crushing strength are better adapted to holding fissures open than are other rocks. A porphyry, a limestone, or a quartzite may have

a high crushing strength and so hold the fissure open and permit mineralization, whereas in shale, which is more mobile, the opening may be closed. It is important, therefore, to note any changes in the character of the lode as it passes from one rock to another.

Fissures more recent than the ore body may cross it and brecciate the ore. These should be carefully studied and located on the mine map. If there has been displacement along them, its character, direction, and extent should, for obvious reasons, be studied with especial care. For convenience the veins have been divided into simple fissure fillings and replacement or metasomatic veins; but it should be borne in mind that the two classes are connected by transition forms.

Simple fissure fillings. The wall rock of an ore body has nearly always been changed by the solutions which deposited the ore, but if the country rock is not extensively replaced by ore minerals the vein may be called a fissure filling. (*a*) The thin, tabular form is more or less characteristic of such a deposit. (*b*) The contact with the country rock is usually sharp and distinct. (*c*) Angular fragments of the walls which were broken off and lodged in the vein may be but little altered, so that their edges still remain sharp. (*d*) Cavities with crusted banding and well-formed crystals pointing to the center may ordinarily be taken as good evidence that the ore was deposited in an open space, and crustiform banding of the vein parallel to the walls usually indicates the same thing.

Many of the fissure veins in the west were formed at moderate depth and in open spaces which presumably connected freely with the surface. Certain minerals are formed under such conditions, and these are discussed briefly on page 112.

Replacement veins. Replacement veins have been formed by solutions which circulated through openings in rocks but which also had the power of dissolving the wall rock and replacing it with ore. All rocks are replaceable under some conditions, but a given solution will not, as a rule, replace all kinds of rock. Replacement veins may therefore be found in igneous rocks, in limestones, in quartzites, or in shales, but it is rarely that all these rocks are replaced in one mining district.

The openings through which the solutions circulated may

have been very small, while the resulting deposit is comparatively large. Still, the deposits are related to fissures, and in a broad way they resemble fissure fillings. Many of them are thin tabular in form, but they are apt to be much less regular in detail than fissure fillings. (*a*) The nodular shape due to irregular swellings along both dip and strike is more or less characteristic. (*b*) The contact with the wall rock is as a rule gradational and not sharp and distinct, as in fissure fillings. (*c*) Small, angular fragments of the country rock surrounded by vein material are not often found in such deposits, except where there has been brecciation since the ore was formed. Obviously, such small pieces of replaceable rock would have been very readily attacked by the replacing solutions. (*d*) Cavities are sometimes found in such deposits, but they have been formed by movement or by solution since the ore was deposited, or they represent unfilled portions of the opening along which the replacing solutions circulated. (*e*) At favorable places, especially where dust has collected on the wall, it may be possible to observe the bedding and jointing of the replaced rock in the ore body, which is in a broad way pseudomorphous after the soluble rock.

Many replacement deposits in limestone follow the original bedding of the rock. This may be due to varying permeability or solubility of beds. Very commonly the roof above such a deposit is a relatively impervious shale. Many bedding-plane deposits, however, seem to be related to planes of movement or bedding-plane faults. The irregular pockets or chimneys of ore replacing limestone may be puzzling, for the fissures or veinlets which lead to them may be very small indeed in comparison with the chamber of ore, but when they are worked out completely some opening through which the solutions may have entered is nearly always found. The minerals of replacement veins do not always differ markedly from those of fissure fillings. Replacement veins as a class are connected by all gradations, both of form and mineralogy, with filled veins on the one hand and with replacement deposits of contact-metamorphic origin on the other.

Replacement deposits of contact-metamorphic origin. These deposits occur in various rocks near intrusive igneous masses, but particularly in limestones. As a rule they are at

or very close to the contact, but some are known several hundred yards away. The ore minerals are so intergrown with silicates characteristic of contact-metamorphic action as to show that all were formed contemporaneously under the influence of the hot igneous mass. In shape the ore bodies are very irregular in detail, and most of them are not clearly related to fissuring. The solutions which deposited them were so hot and under so great pressure that presumably they could penetrate such minute openings as the interstitial spaces between grains or the cleavage cracks of minerals. The deposits, therefore, do not depend so directly on fissuring of the country rock, and they may not be even broadly tabular. Some of the minerals formed in such deposits are discussed below.

Mineralogical study. The mineralogy of the ore should be studied both for scientific and practical purposes. The value of the ore may be ascertained partly by a knowledge of the value of the minerals contained, but frequently assays may be necessary if accurate information on this point be desired. The mineral composition will also suggest suitable metallurgical processes for saving the values, and any data at hand should be recorded for the use of the metallurgist.

Investigation has shown that, although most minerals may form under various circumstances, certain minerals, and particularly certain groups of minerals, are characteristic of certain physical conditions. They may accordingly be used as indicative of the conditions under which ores containing them were deposited. Lindgren * gives the subjoined list of persistent minerals. Since they are formed under many conditions they have little diagnostic value in showing the genesis of a deposit. They are pyrite, chalcopyrite, bornite, arsenopyrite, galena, zinc blende, gold, quartz, fluorite, and muscovite.

Minerals more or less characteristic of contact-metamorphic deposits and veins deposited under great temperature and pressure are, according to Lindgren, pyrrhotite, magnetite, specularite, garnet, andalusite, staurolite, tremolite, diopside, epidote, scapolite, tourmaline, etc.

* The relation of ore deposition to physical condition; Econ. Geology, vol. 2, 1907, p. 105.

The following minerals, in addition to the persistent minerals, may be found in fissure fillings or in replacement veins formed at relatively low pressure: Marcasite, cinnabar, tellurides, silver and copper arsenates and antimonates, stibnite, argentite, chlorite, epidote, adularia, celestite, dolomite, siderite, etc. Among the minerals which may result from secondary enrichment or other processes that are dependent on oxygenated waters are quartz, chalcedony, limonite, pyrolusite, cuprite, kaolin, gold, silver, copper, pyrite, galena, chalcopyrite, bornite, covellite, chalcocite, argentite, with sulphates, carbonates, phosphates, aresenates, and chlorides of the metals.

Secondary enrichment. As a deposit is eroded some minerals go into solution more readily than others. Gold, which is relatively insoluble, may remain, while some of the other constituents are removed. Thus a concentration takes place. As the sulphides oxidize sulphate solutions are formed, and these may dissolve small quantities of the precious metals. If the lode is much fractured the descending sulphates may be reduced, the solutions depositing part of their burden in the cracks of the lode. Thus these fractures in the lode will contain a set of minerals, some of which are different from those of the primary ore. These minerals are included in the list of secondary minerals given above. It may happen that the deposit is explored in depth beyond the point where it is extensively fractured or beyond the point to which oxygenated waters descend; in this case the primary minerals alone will be found. It is obviously important to note the differences in value of the primary and secondary ore, so that some general recommendations as to the desirability of exploration in depth may be made.

Pay shoots. Few veins are payable through the entire length of the strike or dip, the profitable ore being ordinarily limited to a certain portion of the vein. Such masses of valuable ore are called pay shoots and in many veins form tabular bodies of fairly regular elongated outline. The inclination of a pay shoot from the horizontal on the plane of the vein is called the pitch. Its longest dimension is called the pitch length; the term "stope length" refers to its horizontal dimension along the drift following it. Pay shoots may result from primary deposition or from

secondary enrichment by surface waters. The origin of pay shoots is not always easy to ascertain. Many of them may be attributed to mingling of the solutions which deposited the primary ore. The enriched portion of the deposit is often found along or in close proximity to intersections of two fissures that were paths for circulation. An intersection of a fissure and a bed which for chemical and physical reasons is favorable to deposition may also be a locus of enrichment.

Commercial and metallurgical considerations. Wood, water, power, and facilities for transportation are important considerations in mining development. The success or failure of a camp sometimes depends on the success or failure of a metallurgical process. Gold ores of very low grade may be worked by cyanide processes, for the cost of treatment is often not more than $2 or $3 per ton. Silver ores are more expensive to treat, even if the values are in native silver, horn silver, and silver sulphide—minerals which may yield their values on amalgamation in pans without roasting. On the other hand, if arsenates, antimonates, and other undesirable elements are present the ore must be roasted before amalgamation, and the milling costs are then likely to be considerably higher than $6 per ton. Zinc blende in silver ores is detrimental where silver ores are shipped to smelters. Highly siliceous ores are expensive to smelt because they require more flux, but very highly siliceous ores may be used for lining copper converters and for that reason may have additional value. Ores rich in iron and lime have a low treatment charge, for these elements are good fluxes. Although the geologist is not supposed to be a metallurgical expert, he should record such information regarding the treatment of the ores as he can gather in the course of his proper work.

INVESTIGATION OF PLACER DEPOSITS

The study of the general geology in connection with placer deposits differs in no way from that of other field work, except that special emphasis should be laid on the investigation of (*a*) the distribution of the mineralization in the bed rock from which placer deposits have been derived, and (*b*) the distribution and

genesis of the alluvium. In connection with the latter subject the geologist is reminded that a careful search for fossils should be made and also that physiographic studies may yield valuable results.

Every effort should be made to obtain a complete and detailed section of the deposit in which the valuable mineral occurs, from the surface to bed rock. If possible, such a section should be obtained by personal observation and actual measurement. If this is not possible, the observations should be supplemented by data obtained from mine operators, such as records of shafts, drill holes, etc. The section should show the details of (*a*) the cover, or overburden; (*b*) the pay streak, or that portion of a deposit carrying the mineral sought after; and (*c*) the floor upon which the pay streak rests, including a statement of its surface configuration, texture, lithology, etc. In addition to these vertical sections, attempts should also be made to learn the horizontal distribution of the deposits, together with their relations to the topography. In all this work drawings should be made showing detailed vertical and horizontal relations of important features.

One of the most important economic results to be achieved is an estimate of the extent and value of the placer deposits. Such information is none the less valuable because as a rule it is not published, for the geologist can intelligently discuss the probable life of any particular placer-mining district only by having data at hand which will yield some information in regard to both the cubic content of the deposit and the contained values. Effort should therefore be made to ascertain the facts bearing on this subject, and much of the information must necessarily be obtained from the mine operators.

Data bearing on the water supply available for mining purposes should be collected, and in this connection climatic conditions, such as rainfall and temperature, should be considered. As in other mining operations, the question of fuel and timber supply is important and should receive consideration. Facts which will permit the preparation of an accurate account of the history of the discovery and development of the mining district should also be procured while in the field. With this work should go the collection of information on production, especially in the

older districts, where reliable statistics of output are usually not available from published reports. Cost and methods of mining cannot be intelligently discussed if the data in regard to price of labor, transportation, and supplies are not at hand, and these subjects should therefore receive attention. This investigation will necessitate a consideration of the geographic position relative to navigable waters, railways, wagon roads, trails, etc.

INVESTIGATION OF OIL AND GAS FIELDS

A comprehensive knowledge of the general geology—especially of the stratigraphy and structure—is highly essential as a basis for work on oil and gas fields. The stratigraphy must be known in order to interpret well logs correctly and to determine (*a*) the character of the oil or gas bearing stratum and its capacity for holding and yielding the hydrocarbons, and (*b*) the character of the overlying beds and their adaptability for retaining these compounds. The beds concerned as reservoirs and cover should be carefully studied and their thickness determined on the outcrop. This may be at a considerable distance from the oil or gas pool, and the beds should be traced from the outcrop to the pool under investigation by the collection of as many logs of wells in the intervening region as possible. In general the collection of logs of wild-cat wells outside of the productive territory is especially desirable. The importance of structure is such that it must be determined with a much greater degree of accuracy than is generally necessary for other purposes. In most oil and gas fields the structures are not sufficiently pronounced to be traced by determining dips with a clinometer. It is therefore necessary to connect the outcrops of some easily identifiable bed by level lines, which are also tied to all wells whose logs can be obtained. The method of obtaining, from surface observations and well logs, a contoured representation of the oil or gas sand is fully explained by W. T. Griswold in U. S. Geological Survey Bulletin No. 318, and should be familiar to the geologist working in fields to which it is applicable.

In certain oil fields—for example, in southern California, where the oil occurs in post-Paleozoic rocks—the structures, both folds

and faults, may be so strongly developed that they are readily determined by ordinary means and without leveling. In others, as in southeastern Texas, no means are available for determining structure except the well logs and surface relief. The relief should therefore be minutely examined, together with all indications furnished by mineral springs, oil seeps, etc.

Tact is required in obtaining information from operators and drillers. They should be impressed with the benefit to themselves that will result from the assembling of all available information regarding the underground conditions of the field and with the necessity for their coöperation. They should be assured that confidential information will not be divulged under any circumstances and must *never* be given ground for complaint on this score. Explicit permission should be obtained from the owner or superintendent before questioning drillers, but when it is obtained they should be questioned thoroughly.

SCHEDULES

The following schedules cover the more important subjects and classes of deposits which will come under the observation of field geologists. Observations on other deposits should follow the general lines indicated in these schedules.

A. Pure geology:
  1. Description and interpretation of land forms.
  2. Petrology.
  3. Structure.
  4. Glaciers and glacial deposits.

B. Applied geology:
  5. Precious and semiprecious metalliferous ores.
  6. Placer deposits.
  7. Iron ores, ocher, manganese ore, and bauxite.
  8. Stone: (*a*) Sedimentary rocks; (*b*) igneous rocks.
  9. Road materials: (*a*) Rock; (*b*) gravel.
  10. Cement materials and lime.
  11. Clay and shale.
  12. Sand and gravel.
  13. Coal.
  14. Oil and gas.

SCHEDULE 1. Description and interpretation of land forms.

1. Location: District, quadrangle, map reference.
2. Relief.
   - I. General.
     - (1) Amount with reference to sea level and local grade level.
     - (2) Character—plain, plateau, mountain; proportion of each kind.
     - (3) Areal relations (often best illustrated by sketch).
   - II. Component parts.
     - (1) Upland: (*a*) Area of undissected surface and ground plan; (*b*) slope—direction and amount; (*c*) relation to structure and lithology—faults, folds, texture, etc.; (*d*) residual destructional forms —monadnocks, old stream channels, benches, scarps, etc.; (*e*) residual constructional forms —terraces, deltas, dunes, beaches, fans, lava flows, volcanoes, etc.; (*f*) soils and vegetation; (*g*) origin—glacial, marine, eolian, fluviatile, lacrustine, volcanic, etc.
     - (2) Valleys: (*a*) General areal distribution; (*b*) size of main and side valleys and ground plan; (*c*) slope of walls and floor; (*d*) relation to structure and lithology; (*e*) constructional and destructional forms; (*f*) relation of size of valleys to size of streams; (*g*) captures and incipient captures; (*h*) stage of development——young, mature, old, etc.; (*i*) soils and vegetation; (*j*) origin.
     - (3) Spurs: (*a*) Size; (*b*) shape—skeletal, massive, faceted, straggling, etc.; (*c*) slope—smooth, steep, benched, irregular, etc.; (*d*) relation to structure and lithology; (*e*) origin.
   - III. Relation to adjacent regions or types: (*a*) Gradual merging, boundary ill defined; (*b*) terminated by the sea, folding, faulting.

3. Relation of environment to life.
   I. Man: (*a*) Occupations—mining, grazing, agriculture, hunting, etc.; (*b*) constructions—roads, railroads, ditches, buildings, wells, power plants, etc.; (*c*) peculiar characters.
   II. Animals and plants (very brief treatment of larger characters only): Kinds, distribution, peculiar characters.
4. Historical summary.
   I. Physiographic cycles: (*a*) Number and extent; (*b*) stage reached in each—youth, maturity, etc.; (*c*) forms belonging to each; (*d*) origin.
   II. Interruption of cycle caused by (*a*) uplift—doming, folding, faulting, etc.; (*b*) depression—folding, faulting, differential tilting, etc.; (*c*) volcanism—extrusion, eruption, effusion, etc.; (*d*) climatic change—glaciation deglaciation, desiccation, increased precipitation or run-off.

SCHEDULE 2. Petrology

1. Location: (*a*) Quadrangle or other map reference; (*b*) with reference to topography; (*c*) nature of exposures or section, method of measurements—horizontal, vertical, angular.
2. Igneous rocks.
   (1) Petrographic character: (*a*) Mineral composition; (*b*) texture; (*c*) variations in composition and texture; (*d*) specimen numbers.
   (2) Mode of occurrence: (*a*) Form—batholith, laccolith, sheet, dike, neck, etc.; (*b*) size; (*c*) position.
   (3) Relations: (*a*) To other igneous rocks; (*b*) to other forms of the same rock; (*c*) to associated sediments; (*d*) inclusions.
   (4) Contact metamorphism: (*a*) In the igneous rock; (*b*) in the associated rocks—alteration of form, addition of mineral substance, substitution of mineral substance (injection).
   (5) Decomposition: (*a*) Hydrothermal; (*b*) decay; (*c*) mechanical disintegration; (*d*) character of resulting soil.
   (6) Origin (inferred): (*a*) Plutonic; (*b*) effusive.
3. Sedimentary rocks.
   I. Clastic rocks; make numerous detailed measured sections, observing and noting—
      (1) Petrographic character: (*a*) Essential constituent mineral grains—size, shape, color, arrangement, etc.; (*b*) accessory constituents; (*c*) cement—primary or secondary; (*d*) veins—composition, amount, color, etc.; (*e*) color—original or secondary; (*f*) specimen numbers.
      (2) Bedding: (*a*) Beds—thickness, uniformity, regularity, relation to size of grains, etc.; (*b*) bedding planes—mud covered, micaceous, ripple or current marks, mud cracks, rain pits, trails, borings, tracks, fucoids, etc.; (*c*) cross-bedding—dip, direction, etc.
      (3) Fossils; make abundant collections and observe (*a*) distribution; (*b*) position; (*c*) if waterworn; (*d*) in pebbles, etc.

3. Sedimentary rocks—Continued.
   I. Clastic rocks—Continued.
      (4) Concretions: (*a*) Composition—siliceous, calcareous, phosphatic, pyritic, etc.; (*b*) form, distribution, abundance; (*c*) relation to particular beds, to fossils, etc.
      (5) Unconformities: (*a*) By erosion of under beds; (*b*) by overlap of upper beds; (*c*) angle; (*d*) extent—general or local; (*e*) relation to conglomerates.
      (6) Special structures: (*a*) Contorted beds; (*b*) indigenous conglomerates; (*c*) lenses, etc.
      (7) Origin (inferred): (*a*) Source of materials; (*b*) agency of transportation and deposition—marine beach, streams, wind, glaciers, etc.; (*c*) conditions at source of material and point of deposition.
      (8) Classification and correlation: (*a*) Formation, name; (*b*) limits; (*c*) compare and contrast with corresponding sections elsewhere.
   II. Chemical and organic rocks.
      (1) Petrographic character: (*a*) Essential mineralogical constituents; (*b*) accessory constituents; (*c*) texture; (*d*) variations in composition and texture; (*e*) color—original or secondary; (*f*) specimen numbers.
      (2) Bedding: (*a*) Beds—thickness, uniformity, regularity; (*b*) bedding planes.
      (3) Fossils; make abundant collections and observe (*a*) distribution; (*b*) relation to composition of beds, etc.
      (4) Concretions: (*a*) Composition; (*b*) form; (*c*) relations, etc.
      (5) Unconformities: (*a*) Erosion; (*b*) overlap; (*c*) extent, etc.
      (6) Special structures.
      (7) Origin (inferred): (*a*) Source of materials—essential, secondary; (*b*) conditions of deposition—continental, estuary, inclosed basin, playa, flood plain, swamp, etc.; marine, deep sea, littoral, reef, etc.
      (8) Classification and correlation; (*a*) Formation, name; (*b*) limits; (*c*) compare and contrast with corresponding sections elsewhere.

SCHEDULE 3. Structure

1. Location: Map reference.
2. Monoclines.
   (1) Facts to be observed: (*a*) Of the beds—dip, strike, waving, etc.; (*b*) of the structure as a whole—length, regularity, terminations, relation to faults, folds, relation to topography, etc.
   (2) Classification based on observation and inference—simple, warped, faulted (basin-range structure).
3. Folds.
   (1) Facts to be observed: (*a*) Of beds—dip, strike, crumpling, thinning; (*b*) of axes—position, direction, pitch; (*c*) of the folds as a whole—length, regularity, overlapping, relation to topography, etc.
   (2) Classification based on observation and inference—order of magnitude (major or minor), symmetrical or unsymmetrical (axial plane, vertical or inclined), overturned. closed (isoclinal), domed (quaquaversal), cross, pitching, échelon, faulted, etc.
4. Faults.
   (1) Facts to be observed: (*a*) By direct observation where exposures permit—dip or hade (complement of dip), strike, throw, brecciation, drag, slickensides, relation to bedding, relation to other structures (folds and faults), joints; (*b*) by indirect determination where exposures are poor—dip, strike, throw, direction of displacement, length, regularity, relation to other structures and to topography (scarps, stream courses, etc.).
   (2) Classification based on observation and inference—order of magnitude (major or minor), normal (dip toward down-throw), reverse (dip from down-throw), lateral (movement tangential), overthrust, warped, etc.

5. Joints and fissures.
   (1) Facts to be observed: (*a*) Dip, strike, spacing, extent, uniformity (curved or straight), etc.; (*b*) relation to bedding and lithologic character; (*c*) mineralization; (*d*) different systems, character of intersections, relative age; (*e*) relation to other structures, folds and faults, etc.; (*f*) effect on erosion, character of topography, stream courses, etc.
6. Metamorphism (dynamic).
   (1) Facts to be observed regarding structures resulting from metamorphism: (*a*) Attitude—dip, strike, regularity. etc.; (*b*) relation to bedding, local folds, general structures; (*c*) mineral changes—component minerals, original minerals (inferred), nature of change (addition, subtraction, or recombination), parallelism and rotation of minerals, augen, striation, granulation, banding, pitch (pencil structure), etc.

SCHEDULE 4. Glaciers and glacial deposits

1. Location: Map reference or description.
2. Kind: (*a*) Mountain; (*b*) continental.
   A. Mountain glaciers.
      I. Existing glaciers: (*a*) Condition—advancing, stationary, retreating; (*b*) surface, crevasses—character and extent; (*c*) margins—lateral, terminal, relation to névé, bergschrund; (*d*) activity in eroding, transporting, depositing; (*e*) relations to surrounding topography, other glaciers, etc.
      II. Former glaciers:
         (1) Extent: Inferred from (*a*) erosion forms; (*b*) deposits.
         (2) Readvances: Overridden (*a*) outwash deposits, (*b*) lacustrine deposits; (*c*) marsh or forest.
      III. Deposits:
         (1) Moraines: (*a*) Class—terminal, medial, lateral, ground; (*b*) distribution, size, structure, composition; (*c*) relative strength and spacing of inner moraines; (*d*) presence of material foreign to basin.
         (2) Extramorainal deposits (outwash): (*a*) Character, coarseness; (*b*) relation to present stream terraces, etc.
         (3) Glaciolacustrine deposits: (*a*) Beaches, deltas, etc.; (*b*) distribution, structure, composition, etc.; (*c*) relation to other glacial deposits.
         (4) Evidence of relative age: (*a*) Weathering; (*b*) erosion.
      IV. Erosion: (*a*) Striæ; (*b*) rock basins; (*c*) roches moutonnées; (*d*) cirques; (*e*) U-shaped valleys.
      V. Hanging valleys.
   B. Pleistocene continental glaciation.
      I. Direction of movement: (*a*) Striations; (*b*) stoss and lee slopes; (*c*) trend of drumlins, eskers, etc.; (*d*) transportation of erratics.

2. Kind: (*a*) Mountain; (*b*) continental—Continued.
   B. Pleistocene continental glaciation—Continued.
      II. Erosion features: (*a*) Glaciated surfaces—planing, polishing, striation, fluting, chatter marks, gouging, rock basins, roches moutonnées, etc.; (*b*) plucking —relation to joints bedding, schistosity, etc.; (*c*) effects of structure and lithologic character; (*d*) amount—variation.
      III. Ice push: Folding, crumpling, or other dislocation of consolidated or unconsolidated beds.
      IV. Deposits: Composition and structure of each class:
         (1) Moraines: (*a*) Terminal—surface form, relation to underlying glacial deposits, relation to preglacial topography, reëntrants and lobations; (*b*) recessional—relative strength, spacing, relation to other glacial deposits; (*c*) interlobate.
         (2) Drumlins, eskers, kames: (*a*) Form, size, orientation; (*b*) distribution relative to glaciated area; (*c*) to terminal moraines; (*d*) to other drift features; (*e*) to preglacial topography, etc.
         (3) Extramarginal deposits: (*a*) Glaciofluvial—outwash deposits; (*b*) glaciolacustrine—beaches, bars, deltas, etc.
         (4) Associated loess: Relations to glacial drift, topography, and drainage lines.
      V. Age of drift:
         (1) Not overlain by later drift: (*a*) Oxidation: (*b*) leaching; (*c*) solution of limestone fragments; (*d*) decay of crystalline rock fragments; (*e*) induration.
         (2) Overlapping drift sheets: (*a*) Weathering and erosion of earlier prior to deposition of later; (*b*) intercalated soil, peat, forest, marine or lacustrine beds; (*c*) difference in composition due to different origin; (*d*) relation to loess.

SCHEDULE 5. Precious and semiprecious metalliferous ores

1. Location: (*a*) District, State, county, etc.; (*b*) name of claim or mine; (*c*) map reference; (*d*) names of owner, operator, and superintendent.
2. Geologic relations.
   (1) Rock formations (see Schedule 2): (*a*) Igneous, sedimentary, metamorphic; (*b*) contact relations; (*c*) age.
   (2) Structure (see Schedule 3).
   (3) Metamorphism: Regional, contact, hydrothermal.
   (4) Weathering.
3. Ore deposits.
   (1) Outcrop: Leached, enriched, oxidized, yielding placers, etc.
   (2) Form: Tabular, elongated, cylindrical lenticular, pockets, stockworks, irregular masses, etc.
   (3) Attitude: Dip, strike, pitch, etc.
   (4) Position with respect to fissuring, faulting, sheeting, bedding, etc.
   (5) Distribution with respect to (*a*) age and kind of rocks; (*b*) system and age of fissures; (*c*) zones of contact metamorphism, etc.
   (6) Minerals: (*a*) In vein and wall rock; (*b*) vertical variations; (*c*) relations to each other and to fracturing of vein; (*d*) lower limit of oxidation; (*e*) level of ground water.
   (7) Genesis, based on observation and inference.
      (A) Superficial: (*a*) Placers and residual deposits (see Schedule 6); (*b*) deposits formed by precipitation and allied processes.
      (B) Inclosed: (*a*) Contemporaneous with inclosing rocks —sedimentary or magmatic; (*b*) introduced by solutions—contact-metamorphic replacement deposits, replacement veins and related deposits, fissures and other cavity fillings, impregnations and disseminations along favorable beds, etc.; (*c*) pegmatite veins.

3. Ore deposits—Continued.
   (8) Pay shoots: (*a*) Primary or secondary; (*b*) variation in mineralogical character with depth, upper and lower limits; (*c*) position with respect to the deposit as a whole, to fissures (especially to their intersections), and to changes in wall rocks.
4. Conditions affecting mining: (*a*) Topography, accessibility, transportation facilities, building sites, dumps, etc.; (*b*) supplies—timber, water, fuel, power, etc.; (*c*) climatic conditions—working season, frozen ground, etc.
5. Development.
   (1) Surface equipment: (*a*) Hoist—bucket, cage, skip; (*b*) tramways—surface or aerial, length, power.
   (2) Mine equipment: (*a*) Shaft—size, depth, number of compartments, equipment, pumps, etc.; (*b*) incline—slope, direction, length, depth, equipment, etc.; (*c*) tunnel—length, size, etc.; (*d*) winzes, upraises, and chutes—number, position, length, uses; (*e*) levels—number, differences in elevation, depth below surface, etc.
6. Methods: (*a*) Mining—underhand stoping, overhead stoping, filling, rooming, caving and slicing, etc.; (*b*) timbering; (*c*) draining; (*d*) ventilating.
7. Disposition of ore: (*a*) Shipped to smelter—by wagon, rail, water; (*b*) treated in mill—by stamping and amalgamation, cyaniding, chloridizing, pan amalgamation, roasting and pan amalgamation, leaching processes, concentration, etc.
8. History of discovery and development.
9. Production: Total and annual so far as available.

SCHEDULE 6. Placer deposits

1. Location: (*a*) District, State, county, etc.; (*b*) name of claim; (*c*) map reference; (*d*) name and address of owner or operator.
2. Geologic relations.
   (1) Rock formations (see Schedule 2).
   (2) Structure (see Schedule 3).
   (3) Metamorphism: (*a*) Nature—regional, contact, hydrothermal; (*b*) mineralized zones, veins, or other deposits of metalliferous ores.
   (4) Weathering: (*a*) Rock decay; (*b*) rock disintegration.
3. Surficial deposits.
   (1) Overburden or cover: (*a*) Distribution and depth; (*b*) stratigraphic relations; (*c*) character—size, shape, and composition of constituent materials; loose or cemented (nature of cement); (*d*) genesis—transported (agency of transportation and deposition) or residual.
   (2) Pay streak or part of deposit carrying values: (*a*) Number; (*b*) position—vertical, horizontal; (*c*) stratigraphic relations; (*d*) dimensions, shape, etc.; (*e*) character—size, shape, and composition of essential constituent materials; loose or cemented (nature of cement); (*f*) valuable minerals—percentage of each, physical character, size, luster, etc.; (*g*) distribution of values within the pay streak; (*h*) content or value per cubic yard of pay streak.
   (3) Floor or bed rock: (*a*) Configuration, slope, channels, potholes or other irregularities; (*b*) origin of surface—eroded or corraded (agency), glaciated, weathered (under residual deposits), etc.; (*c*) structure of bed rock (particularly jointing, cleavage, etc.); (*d*) mineralogical composition, mineralization, weathering, etc.; (*e*) depths to which values are found in floor or bed rock.
   (4) Ground water (or ground ice): (*a*) Depth and distribution; (*b*) amount and variation.
4. Conditions affecting mining.
   (1) Topography, accessibility, transportation facilities, labor and wages, etc.

4. Conditions affecting mining—Continued.
   (2) Water supply: (*a*) Volume; (*b*) stream gradient; (*c*) relation to placer deposits; (*d*) kind of conduits, dams, reservoirs, etc., necessary and cost of construction.
   (3) Supplies of fuel, lumber, power, etc.
   (4) Climatic conditions: (*a*) Rainfall—amount and distribution; (*b*) working season; (*c*) frozen ground or other exceptional conditions.
5. Methods and costs of prospecting and mining.
   I. Prospecting: (*a*) Methods—pits, shafts, drill holes, drifts, open cuts, etc.; (*b*) cost per unit (cubic yard, acre, linear foot of shaft or drilling, etc.); (*c*) reliability of results.
   II. Mining.
      (1) Preparation of ground: (*a*) Methods—clearing, stripping, ground sluicing, weathering, thawing, sinking, drifting, etc.; (*b*) cost per unit.
      (2) Excavating and handling.
         A. Open cut: (*a*) Manual—hand work with pick, shovel, and barrow; (*b*) hydraulic—ground sluicing, hydraulic elevators, etc.; (*c*) mechanical—horse scrapers, power shovels, lifts, conveyors, trams, hoists, derricks (for handling boulders), etc.; (*d*) cleaning bed rock.
         B. Drift: (*a*) Sinking and drifting—timbering, draining, thawing, etc.; (*b*) hoisting—hand, horse, or power; (*c*) cleaning bed rock.
         C. Dredge: (*a*) Type; (*b*) power; (*c*) capacity.
         D. Cost per unit.
6. Separation of valuable minerals.
   (1) Rocking and panning.
   (2) Sluicing: (*a*) Dimensions, etc., of sluice boxes, grade, riffles, dump boxes, grizzlies, under currents, etc.; (*b*) distribution of values in sluice boxes; (*c*) disposal of tailings.
7. Development: (*a*) Extent of workings, open cuts, shafts, drifts, area dredged, etc.; (*b*) character and value of equipment, including machinery, ditches, roads, building, etc.; annual depreciation of plant.
8. History of discovery and development.
9. Production: Total and annual so far as available.

SCHEDULE 7. Iron ores, ocher, manganese ore, and bauxite

1. Location: (*a*) Map reference; (*b*) name of mine or pit, claim or property; (*c*) names and addresses of owner or operator and superintendent.
2. Geologic relations.
   (1) Rock formations (see Schedule 2).
   (2) Structure (see Schedule 3).
   (3) Metamorphism: Regional, contact, hydrothermal.
   (4) Weathering: (*a*) Decay—character, depth, products; (*b*) disintegration.
3. The deposits; make sketches and photographs.
   (1) Outcrop: (*a*) Character, extent, etc.; (*b*) relation to topography.
   (2) Form: Shape and dimensions—veins, pockets, irregular, bowl shape, dendritic, lenses, beds, etc.
   (3) Attitude: Dip, strike, pitch, etc.
   (4) Position with respect to (*a*) structures—faulting, sheeting, brecciation, jointing, etc.; (*b*) particular beds; (*c*) other deposits of the same or other minerals.
   (5) Overburden: Depth, character, etc.
4. The ore; collect samples for chemical and microscopic examination.
   (1) Composition: (*a*) Essential ore minerals; (*b*) accessory minerals; (*c*) ore siliceous, calcareous, aluminous; (*d*) waste material—clay and boulders of country rock (residual or foreign); (*e*) change with depth; (*f*) change with approach to country rock; (*g*) transition gradual or abrupt.
   (2) Physical character: (*a*) Form—compact, powder, granular crystalline, boulder, gravel, shot, pisolitic, oolitic, concretionary, mammillary, stalactitic, etc.; (*b*) variation, vertically and horizontally.
   (3) Grades of ore, proportion of rock and waste.
   (4) Analyses; secure them whenever possible.

4. The ore—continued.
   (5) Genesis, based on observation and inference: (*a*) Gossan of sulphide deposit; (*b*) oxidation or metamorphism of carbonate; (*c*) weathered outcrop of ferruginous or manganiferous rock; (*d*) deposited as vein filling, replacement, impregnation, or precipitate by (1) surface or (2) spring waters; (*e*) geologic age of deposit.
5. Conditions affecting mining: (*a*) Topography, accessibility, transportation facilities, building sites, settling basins, dumps, etc.; (*b*) supplies—timber, water, fuel, power, etc.; (*c*) climatic conditions—rainfall (amount and distribution), working season, etc.
6. Development (openings): (*a*) Surface pit or cut—size, shape, depth, etc.; (*b*) shaft, slope, or tunnel—size, length, depth, equipment; (*c*) buildings—washer, drying sheds, storage, power house, etc.
7. Methods, actual or practicable.
   (1) Mining: Hand work, power shovel, drilling, blasting, etc.
   (2) Handling: Hand barrow, tram (surface or aerial), conveyor, elevator, chute (with or without water), etc.
   (3) Drainage, timbering, etc.
   (4) Preparation for market: (*a*) Sorting, hand picking, cobbing; (*b*) screening—type and mesh; (*c*) washing—type, capacity; (*d*) drying—air or furnace, type, capacity; (*e*) average cost per unit product.
8. Disposition of ore.
   (1) Uses: (*a*) For metals—iron, manganese, aluminum; (*b*) chemical products; (*c*) pigments, etc.; (*d*) fire brick (bauxite).
   (2) Markets: (*a*) Demand and supply; (*b*) competition; (*c*) freight rates.
9. Statistics.
   (1) Date of opening mine.
   (2) Amount and value of (*a*) average annual production; (*b*) production for last calendar year; (*c*) total production to date.
   (3) Estimate of tonnage remaining in the deposit.
   (4) Royalties, form of lease, option, value of land, etc.

SCHEDULE 8. Stone

A.—SEDIMENTARY ROCKS

1. Location: (*a*) Map reference; (*b*) name of quarry; (*c*) nearest town and railroad station, distance; (*d*) name and address of owner.
2. Petrology.
   (1) Classification: Scientific and trade names.
   (2) Detailed sections, noting for each bed (*a*) thickness and texture; (*b*) color—fresh and weathered; (*c*) banding, spotting, mottling, etc.
   (3) Composition: (*a*) Essential constituents, form and size of grains, character and proportion of cement; (*b*) accessory constituents, especially those that are deleterious, as pyrite, etc.; (*c*) chemical composition—analyses by benches or average of quarry face.
   (4) Weathering: (*a*) Depth; (*b*) character of change; (*c*) character of contact between weathered and unweathered; (*d*) character of surfaces exposed at various distances from original surface for determiniable periods.
   (5) Workability: (*a*) Hardness and toughness, fresh and weathered; (*b*) fracture; (*c*) ease of cutting—when fresh or seasoned, with or across bedding.
3. Geologic relations.
   (1) Stratigraphy: (*a*) Formation names; (*b*) age; (*c*) associated rocks, dikes, etc.
   (2) Structure.
      (I) Of the general region (see Schedule 3).
      (II) In the quarry: (*a*) Dip, strike; (*b*) unconformity, cross-bedding; (*c*) folding, crumpling, fracturing, or faulting of beds; (*d*) joints—systems, spacing, direction, filling, motion, alteration, staining, etc.; (*e*) character of bedding planes—smooth, rough, clean, clay covered, micaceous, stylolitic, etc.

4. Conditions affecting quarrying.
   (1) Outcrops: (*a*) Form and extent; (*b*) relations to topography; (*c*) relations to bedding, structure, etc.
   (2) Overburden: (*a*) Character; (*b*) maximum, minimum, and average thickness.
   (3) Quantity available: Vertical thickness and areal extent of formation.
5. Development.
   (1) Quarry: (*a*) Date of opening; (*b*) type—sidehill, pit; (*c*) form and dimensions; (*d*) drainage.
   (2) Quarrying methods: (*a*) Stripping; (*b*) drilling; (*c*) blasting; (*d*) channeling; (*e*) splitting; (*f*) handling.
   (3) Preparation for market: Equipment and methods for sawing, planing, dressing, polishing, crushing, pulverizing, etc.
6. Utilization, actual and possible.
   (1) Products: Dimensions, rough (riprap), ballast, flagging, curbing, paving, abrasive (grindstones, whetstones, etc.), macadam, concrete, cement, lime, flux, glass, ganister, fertilizer, etc.
   (2) Sizes: (*a*) Obtained; (*b*) obtainable (maximum).
   (3) Tests for strength, hardness, absorption, fire resistance, etc.
   (4) Markets, examples of structures in which product has been used.
   (5) Transportation: (*a*) Shipping point; (*b*) haulage to shipping point; (*c*) mode of transportation to market.
7. Costs and prices.
   (1) Quarrying: (*a*) Average cost per unit quantity; (*b*) wages of unskilled laborers.
   (2) Preparation for market: Cost per unit for sawing, dressing, polishing, crushing, etc.
   (3) Transportation to market, freight rates.
   (4) Prices f.o.b.: Average for various products and grades.
8. Statistics: Quantity and value of (*a*) average yearly production; (*b*) production for last calendar year; (*c*) total production to date.

B.—IGNEOUS ROCKS

1. Location: (*a*) Map reference; (*b*) name of quarry; (*c*) nearest town and railroad station; (*d*) name and address of owner.
2. Petrology.
   (1) Classification: (*a*) Specimen numbers; (*b*) scientific and trade names.
   (2) Microscopic characters: (*a*) Essential minerals; (*b*) accessory minerals, especially such as are deleterious, as pyrite, etc.; (*c*) texture or grain—crypto or coarse crystalline, porphyritic, vitreous, etc.; (*d*) secondary changes due to replacements, contacts with dikes, etc.; (*e*) inclusions, segregations, veins, etc.
   (3) Workability: (*a*) Hardness and toughness—fresh and weathered; (*b*) fracture; (*c*) ease of cutting—when fresh or seasoned, with or across foliation.
   (4) Weathering: (*a*) Depth; (*b*) character of change; (*c*) character of contact between weathered and unweathered; (*d*) character of surfaces exposed at various distances from original surface for determinable periods.
3. Geologic relations.
   (1) Stratigraphy: (*a*) Formation name; (*b*) age; (*c*) associated sedimentary or igneous rocks, dikes, etc.
   (2) Structure: (*a*) Joints—systems, spacing, direction, filling, motion, alteration, staining, etc.; (*b*) rift, foliation, sheets, planes of separation—character, extent, direction; (*c*) exfoliation; (*d*) dikes—character, size, direction, etc.
4. Conditions affecting quarrying.
   (1) Outcrops: (*a*) Form and extent; (*b*) relations to topography; (*c*) relations to structure.
   (2) Overburden: (*a*) Character; (*b*) maximum, minimum, and average thickness.
   (3) Quantity available.
5. Development.
   (1) Quarry: (*a*) Date of opening; (*b*) type—sidehill or pit; (*c*) form and dimensions; (*d*) drainage.
   (2) Quarrying methods: (*a*) Stripping; (*b*) drilling; (*c*) blasting; (*d*) channeling; (*e*) splitting—pneumatic and hydraulic; (*f*) handling.

5. Development—Continued.
   (3) Preparations for market; equipment and method for dressing, polishing, crushing, etc.
6. Utilization, actual and possible.
   (1) Products: Ornamental, dimension, rough (riprap), ballast, macadam, concrete, etc.
   (2) Sizes: (*a*) Obtained; (*b*) obtainable (maximum).
   (3) Tests for specific gravity, strength, absorption, fire-resistance, etc.
   (4) Markets; examples of structures in which product has been used.
   (5) Transportation: (*a*) Shipping point; (*b*) haulage to shipping point; (*c*) mode of transportation to market.
7. Costs and prices.
   (1) Quarrying: (*a*) Average cost per unit; (*b*) wages of unskilled laborers.
   (2) Preparation for market: Cost per unit for dressing, polishing, crushing, etc.
   (3) Transportation to market; freight rates.
   (4) Price f.o.b.: Average for various products and grades.
8. Statistics: Quantity and value of (*a*) average yearly production; (*b*) production for last calendar year; (*c*) total production to date.

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SCHEDULE 9. Road materials

A.—ROCK

1. Location: (*a*) Map reference; (*b*) nearest town and railroad station, distance; (*c*) name and address of owner.
2. Petrology: (*a*) Sample number; (*b*) trade and scientific names; (*c*) maximum, minimum, and average coarseness of grain; (*d*) texture; (*e*) color; (*f*) uniformity; (*g*) alterations.
3. Geologic relations.
   (1) Stratigraphy: (*a*) Formation names; (*b*) age; (*c*) associated rocks, dikes, etc.; (*d*) photograph or sketch showing relations.
   (2) Structure: (*a*) Massive or bedded; (*b*) fissility; (*c*) folds; (*d*) fractures; (*e*) rift.
4. Conditions affecting quarrying.
   (1) Outcrops: (*a*) Form and extent; (*b*) relations to topography, bedding, structure, etc.
   (2) Overburden: (*a*) Character; (*b*) maximum, minimum, and average thickness.
   (3) Quantity available: Approximate cubic yards.
5. Development.
   (1) Quarry: (*a*) Date of opening; (*b*) number of openings; (*c*) form and dimensions; (*d*) drainage.
   (2) Quarrying methods: (*a*) Number and kind of drills; (*b*) method of blasting; (*c*) handling.
   (3) Preparation for market: (*a*) Number and kind of crushers; (*b*) sizes of crushed material produced; (*c*) percentage of each; (*d*) kinds of screens; (*e*) storage facilities; (*f*) weight per cubic yard crushed.
6. Utilization.
   (1) Shipment: (*a*) Shipping point; (*b*) haulage to shipping point; (*c*) mode of transportation.
   (2) Uses: (*a*) Principal markets; (*b*) examples of roads constructed of this material; (*c*) names and addresses of those in charge of construction and maintenance of these roads; (*d*) quality of such roads.

7. Costs and prices: (*a*) Average cost per cubic yard of quarrying; (*b*) of crushing; (*c*) average prices of various grades produced; f.o.b. quarry; (*d*) wages of unskilled laborers.
8. Statistics: Quantity and value of (*a*) average yearly production; (*b*) production for last calendar year; (*c*) total production to date.
9. Tests: (*a*) Results; (*b*) by whom made.
10. Soils, character of, in neighborhood.
11. Other materials available in district for road construction.

B.—GRAVEL

1. Location: (*a*) Map reference; (*b*) nearest town and railroad station, distance; (*c*) name and address of owner.
2. Physical and petrographic character: (*a*) Maximum, minimum, and average size of pebbles; (*b*) are pebbles angular or round; (*c*) kinds of rock constituting pebbles; (*d*) approximate percentage of each; (*e*) character of matrix; (*f*) proportion to pebbles; (*g*) presence or absence of stratification; (*h*) dip; (*i*) clay streaks or pockets; (*j*) do walls of pit overhang or stand up well; (*k*) uniformity of deposit.
3. Geologic relations: (*a*) Age; (*b*) origin; (*c*) associated surficial deposits; (*d*) relations to neighboring hard-rock masses; (*e*) to what extent are the gravels derived therefrom; (*f*) photograph or sketch showing relations.
4. Conditions affecting development.
   (1) (*a*) Form and extent of deposit; (*b*) relation to topography.
   (2) Overburden: (*a*) Character; (*b*) maximum, minimum, and average thickness.
   (3) Approximate quantity available, in cubic yards.
5. Development.
   (1) Pit: (*a*) Date of opening; (*b*) form and dimensions; (*c*) drainage.
   (2) Excavating: (*a*) Mechanical excavators—number, kind, and capacity; (*b*) method of transporting at pit.
   (3) Preparation for market, mechanical devices used for handling and storing material.

6. Utilization.
   (1) Shipment: (*a*) Shipping point; (*b*) haulage to shipping point; (*c*) mode of transportation.
   (2) Uses: (*a*) Principal markets; (*b*) examples of roads constructed of this material; (*c*) names and addresses of those in charge of construction and maintenance of these roads; (*d*) quality of such roads.
7. Costs and prices: (*a*) Average cost per cubic yard for excavating; (*b*) cost of crushing, screening, etc.; (*c*) price of material f.o.b. nearest shipping point; (*d*) wages of unskilled laborers.
8. Statistics: Quantity and value of (*a*) average yearly production; (*b*) production for last calendar year; (*c*) total production to date.
9. Soil, character of, in neighborhood.
10. Other materials available in district for road construction.

SCHEDULE 10. Cement materials and lime

1. Location: (*a*) Map reference or description; (*b*) name of quarry, pit, property, or claim; (*c*) names and addresses of owner superintendent.
2. Material.
   (1) Class: (*a*) Natural cement rock; (*b*) limestone; (*c*) chalk; (*d*) marl; (*e*) shale; (*f*) clay.
   (2) Lithology: (*a*) Mineralogical composition; (*b*) chemical composition and specific gravity (obtain analyses if possible); (*c*) uniformity; (*d*) physical character, color, fracture, hardness, etc.; (*e*) visible impurities, chert nodules, sand grains, and pebbles; (*f*) beds or portions of deposit rejected—cause.
3. Geologic relations.
   (1) Stratigraphy: (*a*) Formation name; (*b*) age; (*c*) position within the formation.
   (2) Structure: Bedding, dip, strike, faulting, jointing, folding, etc.
   (3) Origin (clay): Residual, alluvial, glacial, sedimentary, etc.
4. Conditions affecting development.
   (1) Outcrops: (*a*) Form and extent; (*b*) relation to topography and drainage.
   (2) Overburden: (*a*) Character; (*b*) thickness—maximum, minimum, and average.
   (3) Quantity available: Vertical and areal dimensions.
   (4) Accessiblity, transportation, timber, water, etc.
   (5) Fuel supply: Kind and cost.
5. Development.
   (1) Quarry, pit, or mine: (*a*) Type; (*b*) date opened; (*c*) form and dimensions.
   (2) Methods of quarrying or excavating: (*a*) Stripping; (*b*) drilling; (*c*) blasting; (*d*) dredge or power shovel; (*e*) draining; (*f*) timbering.
   (3) Methods of handling: (*a*) Wheelbarrow; (*b*) tramway; (*c*) conveyor, elevator, etc.

5. Development—Continued.
   (4) Preparation: (*a*) Crushing; (*b*) drying; (*c*) grinding—type, fineness, etc.; (*d*) mixing—local or foreign material, source of gypsum; (*e*) proportions.
   (5) Equipment for excavating, handling and preparing material, and unit costs.
   (6) Burning: (*a*) Kilns—date of erection, type, size, capacity; (*b*) fuel—kind and method of use.
   (7) Cooling and seasoning of clinker.
   (8) Grinding clinker.
   (9) Hydrating lime.
6. Product: (*a*) Natural cement; (*b*) Portland cement; (*c*) lime.
   (1) Brands and trade name.
   (2) Packing: Barrels, bags, or bulk.
   (3) Markets: (*a*) Location and competing supply; (*b*) transportation; (*c*) freight rates.
7. Statistics: Amount and value of (*a*) average annual production; (*b*) production for last calendar year.

SCHEDULE 11. Clay

1. Location: (*a*) Map reference or description; (*b*) name of pit, mine, or property; (*c*) name and address of owner.
2. Character of exposure: (*a*) Natural outcrop; (*b*) pit or mine; (*c*) extent, horizontally and vertically.
3. Detailed sections, noting for each bed—
   (1) Physical character: (*a*) Thickness ; (*b*) color—oxidized or unoxidized, surface stain, mottling, banding, etc.; (*c*) texture; (*d*) fracture; (*e*) hardness; (*f*) slacking; (*g*) plasticity.
   (2) Composition: (*a*) Essential constituents—analyses of separate beds or entire face; (*b*) visible impurities, sand grains (material), concretions (character and composition), boulders, vegetable matter, etc.
4. Geologic relations.
   (1) Stratigraphy: (*a*) Formation name and age; (*b*) position in the formation; (*c*) relation to adjoining rocks.
   (2) Structure: Dip, strike, faulting, jointing, etc.
   (3) Origin: (*a*) Residual mantle from removal of soluble portion of argillaceous rock; (*b*) residual deposit from decay of feldspathic dike or other rock mass; (*c*) sedimentary, evenly stratified by deposition in standing water; (*d*) alluvial, stream laid; (*e*) glacial, unmodified drift.
5. Conditions affecting development.
   (1) Outcrops: (*a*) Form and extent; (*b*) relation to topography and drainage; (*c*) relation to bedding, structure, etc.
   (2) Overburden: (*a*) Character; (*b*) thickness—maximum, minimum, and average.
   (3) Quantity available: Vertical and areal dimensions.
   (4) Accessibility, supplies of timber, water, fuel, etc.
   (5) Association with deposit of other mineral mined: Coal, iron ore, bauxite, mica, etc.
6. Development.
   (1) Pit or mine: (*a*) Date opened; (*b*) type; (*c*) form and dimensions.

6. Development—Continued.
   (2) Mining methods: (*a*) Stripping; (*b*) drilling; (*c*) blasting; (*d*) power shovel; (*e*) drainage; (*f*) timbering.
   (3) Handling: (*a*) Wheelbarrow; (*b*) tramway; (*c*) conveyor, etc.
   (4) Preparation: (*a*) Grinding—type of machines, fineness; (*b*) mixing—local or foreign material; (*c*) washing; (*d*) pugging; (*e*) drying (air or furnace—type); (*f*) drying shrinkage; (*g*) storage.
   (5) Equipment for mining, handling, and preparing product.
7. Utilization at or near point of production.
   (1) Products: (*a*) Structural material—brick, tile, etc.; (*b*) pottery, stoneware, drain tiles, etc.
   (2) Equipment and methods of molding.
   (3) Burning: (*a*) Kilns—type, capacity; (*b*) fuel; (*c*) distribution of heat and temperature; (*d*) length of burn; (*e*) burning shrinkage.
   (4) (*a*) Grades—capacity and output of each for calendar year; (*b*) prices; (*c*) markets; (*d*) shipping facilities; (*e*) freight rates.
8. Shipping raw products: (*a*) Uses; (*b*) markets; (*c*) transportation facilities and freight rates; (*d*) prices at mine.

SCHEDULE 12. Sand and gravel

1. Location: (*a*) Map reference or description; (*b*) name of pit, bank, or property; (*c*) name and address of owner.
2. Character of deposit; make sketches and sections.
   (1) Composition: (*a*) Minerals composing sand grains; (*b*) rocks composing pebbles; (*c*) proportion of various mineral and rock types; (*d*) pebbles fresh or decayed.
   (2) Size: (*a*) Of sand grains; (*b*) of pebbles; (*c*) of boulders; (*d*) proportion of each.
   (3) Shape (rounded, polished, angular, subangular): (*a*) Cf sand grains; (*b*) of pebbles; (*c*) of boulders.
   (4) Induration: (*a*) By pressure; (*b*) by cementation—nature of cement; (*c*) by clay binder.
   (5) Structure of deposit: (*a*) Stratified; (*b*) massive; (*c*) cross-bedded; (*d*) pebbles imbricated.
   (6) Rejected material: (*a*) Stratified clay beds; (*b*) clay lenses; (*c*) clay lumps, balls, etc.; (*d*) peat layers; (*e*) logs, stumps, roots, etc.
3. Geologic relations.
   (1) Origin: (*a*) Agency forming deposit (see Schedule 4); (*b*) source of material.
   (2) Age, stratigraphic and physiographic relations (see Schedule 1).
   (3) Relations to associated hard-rock formations.
4. Conditions affecting development.
   (1) Outcrops: (*a*) Form and extent; (*b*) relation to topography and drainage; (*c*) accessibility.
   (2) Overburden: (*a*) Character; (*b*) maximum, minimum, and average thickness.
   (3) Water: (*a*) Distribution; (*b*) amount; (*c*) drainage.
   (4) Amount available.
5. Development.
   (1) Pit or bank: (*a*) Date of opening; (*b*) form and dimensions; (*c*) drainage.
   (2) Stripping.

5. Development—Continued.
   (3) Excavating: (*a*) By hand; (*b*) mechanical excavators—number, kind, capacity.
   (4) Handling: (*a*) Wheelbarrow; (*b*) tram; (*c*) conveyor—kind, capacity.
   (5) Preparation for market: (*a*) Screening, crushing, washing, drying; (*b*) methods and equipment; (*c*) storage.
   (6) Cost per unit, when obtainable.
6. Uses, actual or possible.
   (1) Structural: Mortar, plaster, concrete, roofing, walls (boulders), etc.
   (2) Glass (get analyses).
   (3) Abrasive: Stone sawing, polishing, etc.
   (4) Traction: Locomotive, trolley, etc.
7. Markets: (*a*) Location; (*b*) transportation facilities; (*c*) freight rates.
8. Statistics: Amount and value of various grades (*a*) produced in last calendar year; (*b*) produced to date.

SCHEDULE 13. Coal

1. Location: (*a*) Map reference; (*b*) name of mine or prospect; (*c*) name and address of owner or operator and mine superintendent.
2. Geologic relations.
   (1) Exposure: (*a*) Kind—outcrop, prospect, mine; (*b*) relation to topography.
   (2) Formation: (*a*) Name; (*b*) age; (*c*) position of coal bed in the formation; (*d*) petrology (see Schedule 2).
   (3) Structure of the region (see Schedule 3).
   (4) Drill records; copy all available and get map locations.
3. Coal bed; make numerous detailed measured sections, observing and noting—
   (1) Roof: (*a*) Material; (*b*) thickness; (*c*) character and strength; (*d*) draw slate; (*e*) any conditions affecting ease or safety of mining.
   (2) Coal: (*a*) Kind—anthracite, bituminous, subbituminous, lignite, cannel, splint, etc.; (*b*) character and appearance—color, luster, texture, fracture, hardness, cleat (direction of faces and butts), effect of weathering, liability to spontaneous combustion, etc.; (*c*) bedded impurities (partings and binders)—character, thickness, position, loose or adhesive, taken or rejected in mining; (*d*) other impurities (sulphur balls, calcite, etc.)—kind, abundance, distribution, ease of separation, etc.; (*e*) irregularities and their effects on mining—rolls, horsebacks, clay veins, faults, wants, dikes, etc.
   (3) Floor: (*a*) Material; (*b*) thickness; (*c*) character; (*d*) tendency to heave; (*e*) adaptability to mining; (*f*) containing stems and roots.
   (4) Collect (*a*) coal samples (see directions, pp. 75–78); (*b*) fossils, especially in roof and on dump.
4. Conditions affecting mining.
   (1) Topography, accessibility, transportation facilities, building sites, dumps, etc.
   (2) Supplies—timber, water, power, etc.
   (3) Climatic conditions, working season, etc.

5. Development (make sketches and photographs).
   (1) Surface equipment: (*a*) Buildings; (*b*) hoist; (*e*) trackage, tipple, bins, etc.
   (2) Mine equipment: (*a*) Shaft—size, depth, compartments, etc.; (*b*) incline—slope, direction, length, depth, equipment; (*c*) tunnel—length, size, etc.
   (3) Workings: (*a*) General plan (get mine map), room and pillar, long wall; (*b*) size of rooms, pillars, gangways, etc.
6. Methods.
   (1) Mining: (*a*) Under cut, sheared, shot from solid, etc.; (*b*) hand or machine (type); (*c*) kind of power, kind of explosive.
   (2) Handling coal in mine: (*a*) Type—mule, rope, motor; (*b*) power.
   (3) Timbering: Amount and kind required.
   (4) Drawing pillars.
   (5) Ventilation: (*a*) Type—natural, furnace, fan; (*b*) gas; (*c*) dust; (*d*) liability to explosion.
   (6) Drainage: (*a*) Type; (*b*) plant; (*c*) amount of water present.
7. Preparation of coal for market.
   (1) Sizing: (*a*) Sizes produced; (*b*) percentage of each; (*c*) kind of screen.
   (2) Cleaning: (*a*) In mine; (*b*) picking; (*c*) washing.
   (3) Handling: (*a*) Mechanical loaders; (*b*) storage—kind and capacity.
8. Utilization, actual and possible.
   (1) Uses: (*a*) Steam; (*b*) domestic; (*c*) gas; (*d*) coking—location, number and type of ovens.
   (2) Markets, transportation facilities, freight rates.
   (3) Waste: (*a*) Benches unmined; (*b*) pillars not drawn; (*c*) slack not used.
9. Statistics.
   (1) Value: (*a*) Coal land; (*b*) royalties (system of leasi g), (*c*) options.
   (2) Production: Quantity and value of (*a*) average yearly production; (*b*) production for last calendar year; (*c*) total production to date.

SCHEDULE 14. Oil and gas (well data)

1. Location: (*a*) Map reference or accurate description; (*b*) name of claim, farm, or lease and designation of well; (*c*) names and addresses of owner, superintendent, contractor, driller; (*d*) date of visit.
2. Geologic relations.
   (1) Formation at surface: (*a*) Name; (*b*) age; (*c*) lithologic character; (*d*) position in the formation.
   (2) Structure: Relation to determined folds, faults, joint systems, etc.
   (3) Topography.
3. Condition of well: (*a*) Productive; (*b*) exhausted; (*c*) dry hole; (*d*) drilling.
4. Well log: if possible make complete copy, which should show—
   (1) Elevation of ground or top of casing.
   (2) Dates: (*a*) Began drilling; (*b*) finished drilling.
   (3) Depth and thickness of each distinct set of beds penetrated and distinguished by the driller (state method of measurement—cable or wire).
   (4) Lithologic character: (*a*) Color, hard or soft, coarse or fine, pebbly, fossiliferous, sticky, tough or brittle, caving, etc.; (*b*) effect on bits; (*c*) examine samples if possible; (*d*) determine meaning of terms used by driller.
   (5) Horizons yielding oil, gas, tar, water, dry rock: Depth and thickness; temperature at various horizons.
   (6) Product: Kind and quality.
   (7) Name of productive stratum, local and geologic.
5. Well record.
   (1) Yield or pressure: (*a*) When first tapped (open, closed, minute); (*b*) after shooting; (*c*) after equilibrium established; (*d*) at time of visit.
   (2) Variation in pressure related to variation in other wells in same pool (indicating open communication or otherwise) and distance to other wells compared.
   (3) Variation in gravity of oil and comparison with gravity in other wells in same pool.

6. Product.
   (1) Gas: Analyses and tests.
   (2) Oil: (*a*) Color; (*b*) odor; (*c*) gravity.
   (3) Oil and water: (*a*) Proportions; (*b*) fresh or salt water.
   (4) Water: (*a*) Fresh or salt; (*b*) capacity; (*c*) head.
   (5) Other substances: Sand, gypsum, sulphur, etc.
7. Methods.
   (1) Drilling: (*a*) Kind of rig; (*b*) special difficulties; (*c*) unit cost.
   (2) Casing: (*a*) Kind; (*b*) sizes; (*c*) lengths of various sizes; (*d*) cost.
   (3) Packing: (*a*) Kind; (*b*) purpose.
   (4) Shooting: (*a*) Date; (*b*) explosive—quantity; (*c*) effect.
   (5) Pumping: (*a*) Kind of pump; (*b*) power; (*c*) cost per barrel.
   (6) Storage: (*a*) Tanks—kind; (*b*) reservoirs; (*c*) capacity.
   (7) Separating oil from water and sludge.
8. Disposition of product.
   (1) Markets: Price (*a*) of oil; (*b*) of gas—to pipe line, to consumer, sold by meter or flat rate.
   (2) Uses: (*a*) Refining—proportion of various products; (*b*) fuel; (*c*) manufacture of gas; (*d*) lubricating.
   (3) Transportation: (*a*) Pipe line—name of owner; (*b*) railroad; (*c*) water; (*d*) rates.
9. Statistics of single well or group of wells in same ownership and pool: Amount and value (*a*) of production for last calendar year; (*b*) of total production to date.
10. History of discovery and development of pool.

APPENDIX I

THE following list of official surveys corrected to date, February, 1909, is inserted especially for the convenience of those who wish to secure information, published or unpublished, relating to the geology of any part of North America.

United States Geological Survey, Washington, D. C.
Organized: 1879. George Otis Smith, Director. Geologic Branch, C. W. Hayes, Chief Geologist. (About 150 persons regularly employed on the scientific force in this Branch.) Topographic Branch, R. B. Marshall, Chief Geographer. Water Resources Branch, M. O. Leighton, Chief Hydrographer. Technologic Branch, J. A. Holmes, Expert in Charge.
Publications: Annual Reports, 1–29; Monographs, 1–50; Geologic Folios, 1–163; Professional Papers, 1–65; Bulletins, 1–376; Water Supply Papers, 1–230; Mineral Resources, 1882–1907.

STATE GEOLOGICAL SURVEYS

Alabama. Geological Survey of Alabama, University, Ala.
Organized: 1873. Dr. Eugene A. Smith, State Geologist.
Publications: Geological map of Alabama, 1894; Reports of Progress, 1873–1888; Bulletins, 1–9, 1886–1907; Separate publications.

Arkansas. Geological Survey of Arkansas, Fayetteville, Arkansas.
Organized: 1907. Prof. A. H. Purdue, State Geologist.
Publications:

Colorado. State Geological Survey, Boulder, Colorado.
Organized: 1907. Prof. R. D. George, Director.
Publications:

California. California State Mining Bureau, San Francisco, Cal.
Organized: 1880; reorganized, 1893. Lewis E. Aubury, State Mineralogist.
Publications: Reports (Annual and Biennial), 1880-1908; Bulletins 1-53, 1888-1898; Maps; Register of Mines and Minerals, with maps (by counties).

Connecticut. State Geological and Natural History Survey, Hartford, Conn.
Organized: 1903. Prof. Wm. North Rice, Middletown, Superintendent.
Publications: Bulletins 1-11, 1904-08.

Florida. Florida State Geological Survey, Tallahassee, Florida.
Organized: 1907. E. H. Sellards, State Geologist.
Publications: Annual Report, 1, 1907-08.

Georgia. Geological Department of the State of Georgia, Atlanta, Ga.
Organized: 1890. S. W. McCallie, State Geologist.
Publications: Administrative Report, 1890-1900; Bulletins 1-17, 1894-1908.

Illinois. State Geological Survey, Urbana, Illinois.
Organized 1905. Frank W. DeWolf, Director
Publications: Administrative Report, 1906- ; Geological Map of Illinois; Bulletins 1-8, 1906-08 (includes Yearbooks 1906-07); Mineral Production of Illinois, 1905-07.

Indiana. State of Indiana. Department of Geology and Natural Resources, Indianapolis, Indiana.
Organized: 1881. Prof. W. S. Blatchley, State Geologist.
Publications: Annual Reports, 11-32, 1881-1907 (continuation of 1-10, Annual Reports of earlier organization, 1869-78); Geological Map of Indiana, 1893.

Iowa. Iowa Geological Survey, Des Moines, Iowa.
Organized: 1892. Prof. Samuel Calvin, Director.
Publications: Administrative Reports, 1894-1905; Bulletins 1-3, 1901-06.

Kansas. State University Geological Survey of Kansas, Lawrence, Kans.

Organized: 1894. Prof. Erasmus Haworth, State Geologist.

Publications: Mineral Resources Bulletins, 1897–9—1902–3; (Reports or Monographs) v. 1–8, 1896–1904.

Kentucky. Kentucky Geological Survey, Lexington, Kentucky.

Organized: 1903. Prof. C. J. Norwood, Director.

Publications: Bulletins 1–7, 1904–07; Report of Progress, 1904–5—1905–6.

Louisiana. Geological Survey of Louisiana.

Organized: 1888. Prof. Gilbert D. Harris, Geologist in Charge, Ithaca, New York, Cornell University.

Publications: Bulletins 1–6, 1905–07; "Geology and Agriculture," Pts. 1–6, in 2 vols., 1892–1902.

Maryland. Maryland Geologic and Economic Survey, Baltimore, Md.

Organized: 1896. Prof. Wm. B. Clark, State Geologist.

Publications: County Reports with maps, 15 vols.; (Monographs dealing with systematic geology of Maryland, Eocene, Miocene, Pliocene, and Pleistocene); (Reports), v. 1–6, 8. 1897–1908.

Michigan. Geological Survey of Michigan, Lansing, Michigan.

Organized: 1838: reorganized, March 26, 1869. Dr. Alfred C. Lane, State Geologist.

Publications: Reports (4°) v. 1–9, 1869–1904; Reports (Annual) of the State Board of Geological Survey, 1–9, 1899–1907.

Mississippi. Geological Survey of Mississippi, Biloxi.

Organized: 1906. A. F. Crider, Director.

Publications: Bulletins 1–4, 1907–08.

Missouri. State of Missouri, Bureau of Geology and Mines, Rolla.

Organized: 1889. H. A. Beuhler, Director and State Geologist.

Publications: Biennial Report State Geologist, 1889–1906; Reports 1–13, 1891–1900; 2d ser., v. 1–8, 1903–08; Bulletins 1–5, 1890–91.

Nebraska. Geological Survey of Nebraska, Lincoln.

Organized: 1901. Prof. Erwin H. Barbour, State Geologist.

Publications: Reports, v. 1–2, 1903–07; Reports 1890–1901, included in Annual Reports Nebraska State Board of Agriculture.

New Jersey. Geological Survey of New Jersey, Trenton.
Organized: 1863. Dr. H. B. Kümmel, State Geologist.
Publications: Annual Reports, 1863–1907; Final Reports, vol. 1–6, 1888–1904; Atlas of New Jersey; Report on Paleontology, vol. 1–4, 1886–1907.

New York. New York State Education Department, Science Division, Albany, N. Y. State Museum.
Organized: 1883; reorganized, 1904. Dr. John M. Clarke, Director and State Geologist.
Publications: Report of State Geologist, 1–27, 1881–1907; Memoirs.

North Carolina. North Carolina Geological and Economic Survey, Chapel Hill.
Organized: 1891. Dr. Joseph Hyde Pratt, Director.
Publications: Biennial Reports, 1891–1904; Bulletins, 1–17, 19, 1891–1908; Economic Papers 1–14, 1897–1907; Reports 1–2, 1905–07.

North Dakota. North Dakota Geological Survey. Grand Forks.
Organized: 1899. Dr. A. G. Leonard, State Geologist.
Publications: Biennial Report 1–4, 1899–1906.

North Dakota. Agricultural and Economic Geological Survey of North Dakota, Agricultural College.
Organized: 1901. Prof. Daniel E. Willard, Director.
Publications: Biennial Reports 1–3, 1901–06.

Ohio. Ohio Geological Survey, Columbus.
Reorganized: 1900. Prof. John A. Bownocker, State Geologist.
Publications: Bulletins 1–9, 1903–08.

Oklahoma. Oklahoma Geological Survey, Norman.
Organized: 1908. Charles N. Gould, Director.
Publications: Bulletin 1, 1908; Circular 1, 1908.

South Carolina. South Carolina Geological Survey, Charleston.
Organized: 1902. Dr. Earle Sloan, State Geologist.
Publications: Bulletin (4th ser.), No. 1–2, 1904–08.

South Dakota. South Dakota Geological Survey, Vermilion.
Organized: —. Prof. E. C. Perisho, State Geologist.
Publications: Bulletins 1–3, 1894–1902.

Vermont. Geological Survey of Vermont, Burlington.
Organized: 1896; reorganized, 1900. Prof. George H. Perkins, State Geologist.
Publications: Biennial Reports 1–6, 1898–1908.

Virginia. Virginia Geological Survey, Charlottesville.
Organized: 1904. Prof. Thomas L. Watson, State Geologist.
Publications: Bulletins 1–3, 1905–06.

Washington. Washington Geological Survey, Seattle.
Organized: 1901. Prof. Henry Landes, State Geologist.
Publications: Annual Report of State Geologist, 1901–02, 2 vols.; Biennial Reports Board of Geological Survey, 1901–03, 1 vol.

West Virginia. West Virginia State Geological and Economic Survey, Morgantown.
Organized: 1897. Prof. I. C. White, State Geologist.
Publications: Report 1897–98; Biennial Report 1901–02, 1 vol.; Bulletin 1, 1901; (Economic Reports), 1, 1A, 2, 2A, 3, 1899–1908.

Wisconsin. State of Wisconsin Geological and Natural History Survey, Madison.
Reorganized: 1897. (First Survey, 1853–1879.) Dr. E. A. Birge, Director.
Publications: Biennial Reports 1–5, 1897–1906: Bulletins 1–20, 1898–1908; Hydrographic maps; Road Pamphlets 1–4, 1907.

Wyoming. Wyoming Geological Survey, Cheyenne.
Organized: 1901. Henry C. Beeler, State Geologist.
Publications: Reports 1903–06, 2 vols.; Wyoming Mines and Minerals, 1907.

CANADIAN SURVEYS

Canada.—Department of Mines, Geological Survey Branch, Ottawa.
Organized: 1842. R. W. Brock, Director; Joseph Whiteaves, Assistant Director and Paleontologist; John Macoun, Assistant Director and Naturalist; Clovis O. Senecal, Geographer and Chief Draughtsman.
Publications: Annual Reports, 1842–date; Maps; Miscellaneous publications.

Ontario. Bureau of Mines, Toronto.
Organized: —. Thos. W. Gibson, Deputy Minister of Mines; Willet G. Miller, Provincial Geologist.
Publications: Reports of Bureau of Mines, vols. I–XVI.

MEXICAN SURVEYS.

Mexico. Instituto Geológico Nacional, 5a Cipres, Mexico D. F.
Organized: 1893. José G. Aguilera, Director; Juan D. Villarello, Vice-Director; Dr. E. Böse, Chief Geologist.
Publications: Boletin 1–24 (4°), 1895–1906; Parergones (8°), vol. 1–2, 1903–08; Miscellaneous maps.

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